Harry L. Mosser

SWITCHING EQUIPMENT
FOR
POWER CONTROL

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BY

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First Edition
Second Impression

McGRAW-HILL BOOK COMPANY, Inc.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST., E. C. 4
1921

THE MAPLE PRESS YORK PA

PREFACE

Switching equipment for power control forms a very essential part of any plant for the production or distribution of electrical energy. This equipment has been aptly described as the "brain" of the electrical system as it performs all of the duties of direction and control that are so vital to the proper functioning of the system.

Information on the subject of switchboards and switching equipment can be found in very condensed form in certain electrical handbooks, and specific data on definite appliances can usually be obtained from manufacturers. Articles in the technical press also furnish a certain amount of data on this subject, but there has been no American book dealing with the general subject.

Demand for a book on this subject has lead the author to undertake its preparation basing it largely on his own articles which had previously appeared in the switchgear and control sections of the "Penders Handbook for Electrical Engineers" and in the *Electric Journal, Electrical World, Southern Electrician, Electrical Age,* etc. These have been partly re-written and brought up-to-date.

Manufacturer's publications have been consulted freely and some of their descriptive matter utilized bodily or reworded to adapt it to this book. The attempt has been made to select such information as would be of the greatest use to the largest number of readers and that would embody standard practice rather than special applications.

Thanks of the author are due to various publishers for their permission to utilize his material previously published, and to the various electrical manufacturers for the data they furnished. Grateful acknowledgment is also made to the author's many friends and associates for information supplied and suggestions as to subject matter and arrangements of material.

The main object of this book is to furnish the actual switchboard operator the information that will help him to keep the equipment in his care in the best operating condition, by explaining what should be expected of the apparatus and equipment. It will also assist him in the selection and installing of new material.

The secondary object is to help the student of electrical engineering in a technical school to get a better understanding of this branch of the art and to appreciate how the switching equipment ties together the various generators, transformers, feeders, etc., that make up the component parts of a generating and distributing system.

Consulting engineers and others will find enough of the theoretical features to give them an understanding of the functions and limitations of the various devices. Such an understanding will facilitate specifying equipment that can be readily obtained and that will operate satisfactorily under actual conditions.

The arrangement of this book has been based on the idea of first describing the switching apparatus, approximately in the order in which the various devices were developed. This is followed by considering the main connections desired in a power plant and the means for carrying out the connections so as to obtain the maximum amount of security and flexibility with the minimum outlay. Switchboard panels, control desks, etc., are considered next with the location of breakers, bus structures, etc., and the general arrangement of the part of the power plant devoted to switching equipment.

Description of apparatus has been confined almost exclusively to present day standards to keep the subject matter down to a reasonable length, but a few references have been made to some of the older types of apparatus to show the progress of design.

American practice forms the basis for the descriptions and most of it is the practice of the largest electrical manufacturers. The attempt has been made to include descriptions of apparatus of other important builders, but it has been impossible to describe all of the apparatus of all the builders. The data has been obtained from various sources and the most readily available material has been used.

STEPHEN Q. HAYES.

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CHAPTER I

SWITCHES

KNIFE SWITCHES

Definition.—Switches may be considered as devices for mechanically opening up an electric circuit and their design is based primarily on the following features: They must, when closed, carry their rated current without excessive drop or excessive heating and must take care of the overloads met in practice; they must, while being opened, be designed to prevent or render harmless any arcs that may be formed; they must, when open, insulate all live parts for maximum potential in a permanent manner.

Early Types.—The earliest types of switches consisted of metal plates mounted on wooden blocks and connected together by a plug inserted between them. The weakness of this first design was the proximity of the plates and the tendency for an arc to hold on when the plug was withdrawn. The next step was to increase the distance between the two stationary contacts and to use a movable plate attached to a handle for bridging the gap between these stationary contacts. To avoid losing this movable plate, the next step was to hinge it to one of the contacts and from this beginning the present knife switches have been developed.

Underwriters Rules.—The rules of the National Board of Fire Underwriters relative to knife switches state: "All switches must have ample metal for stiffness and to prevent rise in temperature of any part of over 30 degrees Centigrade at full load, the contacts being arranged so that a thoroughly good bearing at every point is obtained with contact surfaces, advised for pure copper blades, of about 1 square inch for each 75 amperes." As the result of many tests the Underwriters settled on certain minimum spacings between points of opposite polarity for various currents and voltages of 250 D.C. or 500 A.C. and for 600 D.C. Most switches are designed to meet these requirements as to temperature rise, contact surface, spacing and other recommendations.

Multiple Blades.—Up to about 1200 amperes in capacity knife switches are usually made with single blades, while for larger capacity two or more blades per pole are supplied in order to secure sufficient contact surface without making the blades and jaws of abnormal width.

Quick Breaks.—"Auxiliary breaks" or "quick break attachments" are furnished in many cases so as to make it impossible to draw a dangerous arc by opening the switch slowly. These quick break attachments are made in many forms.

Current-carrying parts of a well-designed switch consist of a high grade of drawn copper of guaranteed conductivity. The sectional areas and contact faces of all sliding and stationary parts are calculated in accordance with the best practice, and a liberal allowance is made for overloads.

Temperature.—The current-carrying parts adjacent to the contacts will carry their full-rated current continuously with a maximum temperature rise of either 20 or 30 degrees Centigrade above the temperature of the surrounding atmosphere, depending on the class of service.

The rear connected switches of 1200-ampere capacity and larger are given a lower rating for alternating current than for direct current and are not guaranteed to carry more than their rated current.

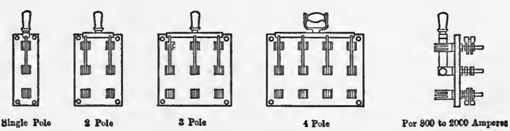


Fig. 1.—Typical knife switches.

Momentary Current.—The maximum momentary current passing through knife switches should not be greater, owing to mechanical and electrical limitations, than 50 times their normal 60-cycle 20-degree ampere rating. If the switches will be subjected to greater current momentarily than this, switches of larger normal rating (amperes) should be used as they are both mechanically and electrically stronger.

Front Connected.—Front connected knife switches are listed by most makers up to 1200 amperes; for maximum voltages of 250 volts D.C. or A.C., 500 volts A.C., and 600 volts D.C. or A.C.; with and without quick break blades; fused and unfused; single and double throw.

Rear Connected with Round Studs.—These switches are listed in capacities up to 1200 amperes not fused and 600 amperes fused; for maximum voltages of 250 D.C. or A.C., 500 A.C. and 600 D.C. or A.C.; with and without quick break blades; single and double throw.

Rear Connected with Laminated Studs.—These switches are furnished with the conductor slots in the studs horizontal, or vertical as required. They are listed in capacities from 1600 amperes to 6000 amperes for 250 volts D.C. and 500 volts A.C., and 600 volts D.C. and A.C. without fuses.

Handles.—Spade handles are regularly furnished on all 4-pole switches and on all 3-pole above 600-amperes capacity; they are also regularly furnished on single and 2-pole switches with laminated studs. All other knife switches have straight handles.

Fuses.—Fused switches are arranged for National Electrical Code Standard enclosed fuses. All switches that are fused on the hinge jaws have high jaws to allow the switch handles and blades to *lie flat* on the fuses. All switches that are fused on break jaws have high break jaws to allow clearance between handle and fuses.

Switch Studs.—The smaller capacity switches are made both rear connected and front connected, while the larger switches are almost invariably made rear connection. Up to approximately 1200 amperes the standard studs for rear connected switches are circular and the switch studs are attached to their bases by nuts screwed on these circular studs. Additional nuts are provided for clamping strap connections or terminals. For the larger capacity switches employed on low voltage boards, strap connection are almost invariably used and to facilitate the employment of the strap connections the switch studs are frequently made laminated. A modification of the laminated studs made with copper bars employs copper studs cast under high pressure by means of which the conductivity of the cast studs is approximately 90 per cent. that of rolled copper. With the laminated stud switches the laminations can be arranged for the horizontal or vertical plane as is best adapted to the wiring.

Knife Switches for A.C. Service.—Up to 800 amperes there is no appreciable difference in the heating of knife switches on direct current or alternating current. For larger capacities it is found that for the same temperature rise it is necessary to derate the larger knife switches for 60-cycle service. The constants vary with different designs and different capacities. The 30-degree rise is that covered by the Code while the 20-degree rise is the one that is desirable for hot switchboard rooms.

Figure 1 shows the outlines of rear connected knife switches for D.C. ratings up to 1200 amperes. The ratings given are based on D.C. 30-degree rise and the same ratings are used on the switches up to 800 amperes for 20 degrees and for 25- and 60-cycle service. For the 1200-ampere size the 30-degree rating for 25 or 60 cycles is 1100 amperes while for 20-degree rise the rating is 1000 amperes for D.C. or A.C. With laminated studs the ratings are as follows for the larger switches:

MAXIMUM AMPERES

30 Degree rating			20 Degree rating		
D.C.	A.C.		D.C.	A.C.	
	25 Cycles	60 Cycles		25 Cycles	60 Cycles
1600	1400	1200	1300	1200	1100
2000	1800	1600	1600	1400	1200
3000	2600	2200	2400	2000	1800
4000	3400	2800	3200	2700	2200
6000	4200	3800	4500	3200	2800

Motor-starting Knife Switches.—Shown in Fig. 2 are used as a simple and inexpensive method of starting synchronous converters from the direct-current end and direct-current motors of large capacity having starting conditions that will permit cutting out the starting resistance in three steps. They are intended for starting conditions only, being rated in terms of the starting current, and a short-circuiting line switch or circuit breaker should be used to carry the running load. They will, however, carry one-fourth their rated current continuously, so that the short-circuiting line switch can be omitted where the full-load current is only one-fourth of the starting current rating of the switch.

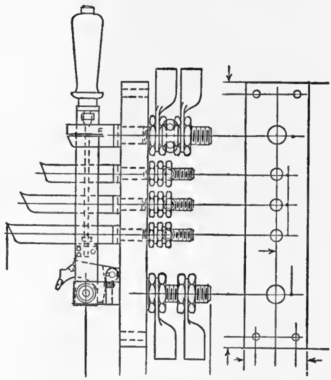


Fig. 2.—Motor starting knife switch.

To start a motor the switch blade is thrown into the first jaw and, after a moment's pause between steps, into each succeeding jaw until the last is closed. The short-circuiting line switch, where used, is then thrown in. The circuit should always be opened by opening the line switch or circuit breaker.

These switches have four sets of contacts of such length that the switch blade makes contact with each set in succession. Each switch has four blades, a construction that allows of ample ventilation and reduces the depth of the switch from the switchboard.

To prevent large machines being started too quickly by throwing the switch through all the positions without stopping on any one position, a ratchet device is provided on the 1200, 2400, and 3600-ampere switches.

Field-discharge switches are used in the field circuits of generators to serve as means of opening and closing the field circuit. Just before the knife blades of the switch leave the contact jaws, an auxiliary blade makes contact in such a way that the discharge resistor is connected across the field winding, thus allowing the inductive discharge of the field winding to die out gradually.

Field-transfer switches are used for transferring the field circuits of synchronous converters or generators from one source of excitation to another without opening the supply circuits, where there is not likely to be a difference of potential between the two sources. Where such a difference is likely to occur, a transfer switch with additional jaws for inserting a limiting resistor between the supply circuits should be used. They are used especially where it is necessary to transfer a synchronous converter or a generator field circuit from the bus bars to the armature for self-excitation or to a direct-connected exciter as with synchronous converters or synchronous motor-generator sets started from the direct-current side.

The field-transfer switches are operated on the rocker principle with their blades so shaped that just before one side leaves the contact jaws the other makes contact with its jaws. Thus the field circuit is not opened. The single-pole switches are used particularly in railway service using grounded return.

The remote-control type has the switch mounted on a sub-base in the rear of the panel and connected through levers to an operating handle mounted with a cover plate on the switchboard panel. The operating handle has a latch, by means of which the switch may be locked in the open or closed position at the will of the operator.

The safety-first enclosed knife switch is used in steel mills, factories, mines, and similar places employing men having practically no knowledge of electricity and its attendant risks. The danger to life and the employer's liability for death or injury to a man touching a live part of the control switch or to a repairman inspecting a motor, have made an absolutely safe switch almost a necessity.

The safety-first enclosed knife switch case contains an ordinary single-throw knife switch with enclosed fuse holders at the hinged end. These are mounted in an exceptionally strong iron box, certain makes having a partition that separates the switch blades from the fuse holders. The box is provided for conduit connections. The upper or switch compartment can be opened only by removing two machine screws, and padlocks when used; it is necessary to open this compartment only when making connections and in case of inspection or repairs, as the switch is opened and closed by an operating handle on the outside of the box, acting through a shaft and lever within. The lower or fuse compartment contains the only parts that need be handled—fuses to be replaced when blown out. The door of this compartment is so interlocked with the switch that it can be opened only when the switch is in the open position, and with this door opened, the switch cannot be closed. Consequently the fuses can be handled only when disconnected from the live line. Due to the partition, it is impossible to reach the live parts in the switch compartment. A spring is sometimes provided to keep the door of this compartment closed. The operating handle can be locked with the switch in the open position, thus preventing tampering by unauthorized persons and protecting repairmen working on the circuit.

PLUG SWITCHES

Plug switches were predecessors of the knife type of switch but the ordinary plug type as first built did not have sufficient spacing between contacts and could not be used to open the circuit under load, and could not be built to carry more than 200 or 300 amperes at the most, so that the design of the knife type of switch outstripped the plug. For certain classes of service, however, the plug switch can be utilized to advantage. Various types of plug switches have been developed by various manufacturers and at one time they were used to a considerable extent for A.C. service up to 200 amperes at 2400 volts in the form of "plunger switches."

In the single-pole designs plug-type switches are still used to a slight extent for arc lamp service and similar cases where a high voltage switch of small current capacity rating is wanted. These switches consist essentially of a tube of fibre or similar material, with socket contacts at each end, mounted on the rear of a panel, and a plug consisting of a metallic rod or tube with an insulating handle. The plug when inserted through a hole in the switchboard connects together the contacts at each end of the tube.

Plug-type instrument switches are used for connecting a voltmeter, ammeter, or power factor meter to any one of several generators, and for making the multi-point connections required when synchronizing generators.

For switchboard-voltmeter circuits the receptacles are made with 2, 4, 6, or 8 points. The metal parts are recessed in a bushing of insulating material so as to avoid danger of accidental short circuits. The separate sockets are spaced in such a way that the plug cannot be inserted incorrectly, it thus being impossible to short-circuit the line through the plug.

For Portable-voltmeter Circuits.—Receptacles and plugs are used for connecting a portable voltmeter in parallel with the switchboard voltmeter for the purpose of testing the accuracy of the latter. A lamp cord running through the end of the handle of the plug connects with the portable instruments, while the receptacle is permanently wired up to the switchboard instrument.

For A.C. Ammeter Circuit.—Another type of plug is used for testing the switchboard ammeter. It fits the same receptacle and is identical with a transfer plug except that it has a lamp cord which makes connection through the handle with the portable ammeter. This plug, when inserted in the receptacle, connects the portable ammeter in series with the switchboard ammeter, in the current transformer secondary circuit.

By the use of transfer plugs and receptacles, one ammeter can be used to indicate the current in each phase. The primary of a current transformer is connected in each phase of the circuit and the secondary goes to the line terminals of its receptacle where it is normally short-circuited. When the plug is inserted in a receptacle the ammeter is connected in that circuit.

For ground detector circuits plugs and receptacles are used with high potential push buttons, and a voltmeter or lamp to indicate the existence of a ground on 1, 2, or 3-phase circuits. For circuits of voltage over 125, switchboard transformers or the necessary lamps in series are required.

Push-button switches are sometimes used for transformer type ground detectors, engine-room signals and similar devices. These are frequently arranged as the equivalent of double-throw switches normally maintained in one position by a spring to make one set of connections, and making other connections when pushed in by hand or some of the switch gear mechanism.

For synchronizing circuits, plugs and receptacles (Fig. 3) are used for making connections to synchronizing instruments. Certain types have, in addition to the contacts for making the connections to the synchronizing instruments, a set of contacts of 40-amperes capacity through which the control circuit of the electrically operated generator circuit breaker may be connected so that the generators can be thrown on the bus bars only when the synchronizing instruments are in circuit.

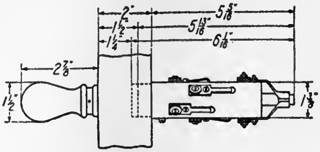


Fig. 3.—Synchronizing plug and receptacle.

DRUM SWITCHES

Drum-type instrument switches are used for connecting one instrument to any one of several circuits and for making the multi-point connections required when synchronizing generators.

Construction.—Ruggedness and compactness are salient features of the best instrument switches in a typical design. Movable contact members, securely mounted on a substantial bakelite-micarta drum, engage with stamped contact fingers as the drum is rotated to the right or left. The switching element is housed in a substantial bakelite-micarta tube. A segment of the housing is easily removable for inspection and adjustment.

The operating key is of black moulded material with a polished black finish; the dial-plate markings are polished copper, on the raised parts, with a black-mat background; and the housing is finished in dull black.

All of these instrument switches, with the exception of the ammeter and thermocouple switches, have removable keys or handles. These keys are labeled and so constructed that they cannot be inserted in the wrong switches.

Ammeter switch is so made that with one ammeter, one ammeter switch and two or more current transformers on a polyphase circuit, the ammeter can be connected so as to read the current in any phase. Switching contacts are so arranged that the current transformer secondary circuits are never opened. For connections see Fig. 4.

Thermocouple switch is built so that with one switch per generator, the potentiometer or temperature indicator can be con-

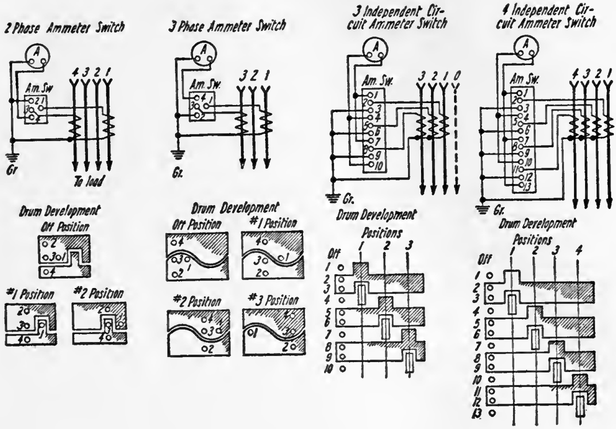


Fig. 4.—Ammeter switch connections.

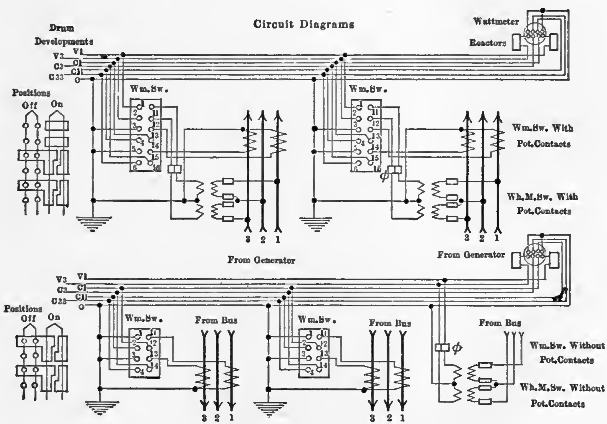


Fig. 5.—Wattmeter switch connections.

nected so as to read the temperature in any couple or search coil on any machine.

Voltmeter switch is so made that with one voltmeter switch for each polyphase circuit, one voltmeter and, for service above 600 volts, the necessary potential transformers, the voltmeter can be connected to read the voltage on any phase of any circuit. One key is required for each voltmeter and its group of switches. If more than one group of voltmeter and switches is desired, each group can be supplied with a different key arrangement.

Frequency-meter switch is arranged so that with one frequency meter the necessary potential transformers and one switch for each bus system, the frequency can be read on any bus system. One key is required for each frequency meter.

Wattmeter, watt-hour meter, power-factor meter and reactive-factor meter switches are made so that with one instrument, one switch with proper labeling and key arrangement for each single or polyphase circuit, and the necessary instrument transformers, readings can be taken on any circuit. One key is required for each instrument. For connections see Fig. 5.

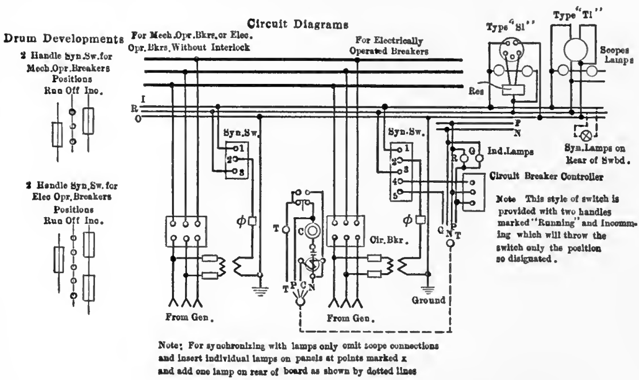


FIG. 6.—Connections for synchronizing between machines.

Synchronizing switch for synchronizing between machines is so made that with one synchronoscope equipment, one switch for each machine, and the necessary potential transformers, a synchronizing indication can be obtained between any two machines. One running key and one incoming key are required. The running key is to be placed in the synchronizing switch of one of the machines running and can be turned to the running position only; the incoming key is to be placed in the synchronizing switch of the machine being brought in and can be turned to the incoming position only. Each switch has a running and an incoming position. For connections see Fig. 6.

Synchronizing switch for synchronizing between machine and bus is so made that with one synchronoscope equipment, one switch for each generator on a single-bus system and two switches for each generator on a double-bus system and the necessary potential transformers, a synchronizing indication between the bus and any incoming machine can be obtained. One key only for each board is required. Synchronizing switches are built with and without interlock contacts for the closing circuit of electrically operated circuit breakers. For connections see Fig. 7.

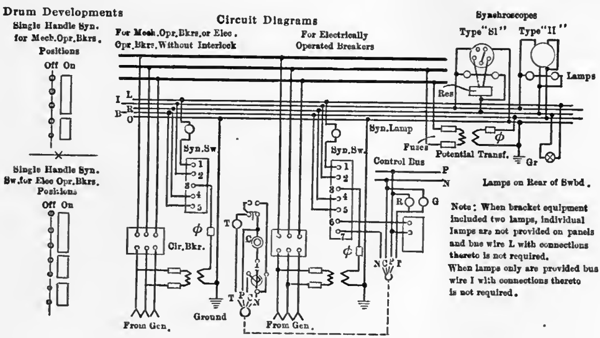


FIG. 7.—Connections for synchronizing to bus.

CONTROL SWITCHES

Control switches of different types have been developed for the control of electrically operated devices of various kinds, put into service, and then superseded by later devices.

The first control devices were small single-pole, double-throw knife switches, usually made with a spring to return the blade to the open position after being thrown one way or the other. A modification of this switch had a little celluloid plunger located in an enlargement of the blade, colored red on one end, green on the other, and of slightly greater length than the depth of the blade. The color of the end that was projecting from the blade showed the last position to which the switch had been thrown.

The disadvantage of this type of control switch was the possibility of its being accidentally operated by the station attendant when reaching for another device, and the trouble arising from the live contacts on the face of a switchboard where there were no other live parts on the front.

G. E. Control Switch.—A push button for closing a control circuit and another for tripping was an early scheme adopted to do away with the live contacts on the front. The push button had the disadvantage of being liable to accidental closing by the

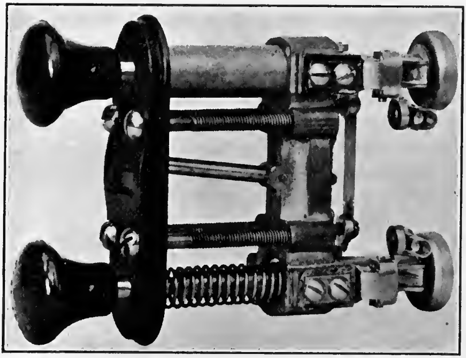


FIG. 8.—General Electric Co. pull button switch.

switchboard operator so a "pull button" was substituted for a push button and the twin pull button shown in Fig. 8 has been standardized by the General Electric Company for control devices on switchboards.

By using pull buttons in place of push buttons there is little likelihood of the attendant operating the device unintentionally when cleaning or working about the switchboard. Red and green indicating lamps with prismatic lenses are used for signals and a little target, colored red and green and located between the buttons, shows the last movement that has been made, so that if the target shows one color and the indicating lamp another the breaker has tripped automatically.

Lewis and Roth combination control switch and indicating device put on switchboards made by them embodies the essential features of no live parts on the front of the board, a position indicator with red and green target, the usual red and green indicating lamps, a spring return to the off position, great compactness, and good appearance when worked into a miniature bus arrangement.

Westinghouse Control Switch.—The Westinghouse Electric & Manufacturing Company first tried pull-button switches but soon shifted over to a drum-control switch that possessed many features that it was difficult to embody in a pull-button device. By varying the drum development and the number of contact fingers, various interlocks could be made and one control switch could handle the three electrically operated breakers for motor starting, the forward and reverse motion with limit switches for governors, valves, rheostats, etc.

Their latest control switch is built along modern and latest practice in controller design, having an insulated square shaft for carrying the moving contact segments with special view to securing space economy while having due regard for proper insulation, as shown in Fig. 9.

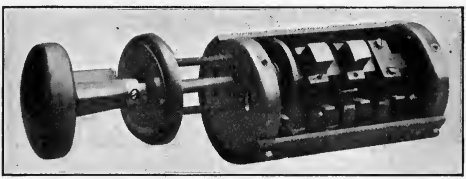


Fig. 9.—Westinghouse drum control switch.

These control switches have been designed for the control of circuits governing the operation of solenoid operated switches and circuit breakers or their control relays, solenoid operated rheostats, motor operated rheostats, motor operated engine and turbine governors, and motor operated feeder-potential regulators.

The adaptability of the control switch to a variety of special requirements insures a neat and uniform appearance of equipment on the front of the switchboard. As an aid in selection for the switchboard operator, control switches for circuit breakers are provided with handles of a different shape than those of the other control switches.

These control switches will successfully handle current values of considerable magnitude. However, where the current demands, of closing solenoids in particular, are in excess of certain values, a control relay should be interposed between the controller contacts and the solenoid. In general, control relays are not usually required in the trip-coil circuit of breakers.

Construction.—Ruggedness and compactness are salient features of control switches. Advantage has been taken in their design of the years of successful operation and experience on railway controller contacts. Rugged stamped contact fingers of the same type as employed on railway controllers are used; the advantages of the horn-gap construction inherent in this design are well known. Movable contact members mounted on a square insulated shaft engage with stationary spring-contact fingers as the shaft is rotated to the right or left. The switching element is housed in a substantial bakelite-micarta tube, which provides a simple rigid insulating structure. A segment of the housing is easily removable for inspection and adjustment.

Space Requirements.—The switches with their indicating lamps can be mounted $3\frac{1}{2}$ inches between vertical center lines and 7 inches between horizontal center lines, or 7 inches between vertical center lines and $3\frac{1}{2}$ inches between horizontal center lines. This feature is in keeping with modern requirements of space economy for switchboards.

Telltale.—All control switches are provided with a mechanical indicating device that shows the last manual operation of the control switch. When the handle is released, the switch automatically returns to the neutral (central) position.

Lamp Cut-out.—Several designs of switches for the control of solenoid operated breakers, embodying a signal lamp cut-out are made. The oval handle on these switches may be turned past the trip position to a lamp cut-out position which is 90 degrees from the neutral (central) position and there latched in place; this, therefore, closes the circuit to trip the breaker, and then opens both the trip circuit and the indicating lamp circuit with the breaker "locked" in the open position. On double-bus or relay-bus systems, this permits cutting out all breakers and lamps on the bus not used; the horizontal position of the control handles when set this way is very readily observed by the operator.

Lamp indicators are connected in the control circuit of electrically operated circuit breakers to indicate whether the breaker is open or closed.

Operation.—The lamps are usually so connected with the signal switch on the breaker that when the breaker is closed the red indicator will be lighted and when the breaker is open the green indicator is lighted. On one style of the control switch, an additional indicator is so connected to the signal and control switches that when the breaker is tripped automatically this indicator is lighted and remains lit until the control switch turns to the "close" or "open" position; this is the equivalent of the mechanical indicating device that is self-contained on certain control switches.

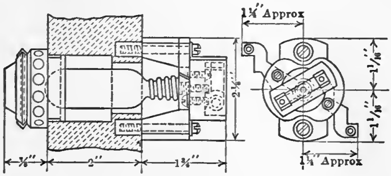


Fig. 10.—Lamp indicator.

Construction.—Each indicator, shown on Fig. 10, consists of a receptacle projecting through the switchboard for holding a candelabra lamp, and a lens holder with a special prismatic lens. The lamp is removable from the front of the panel and the receptacle is provided with a glass-tube fuse at the back of the board. The lens holder is pushed into the end of the receptacle from the front of the board and is held firmly by spring clips. A special feature of the lens is the prismatic projection extending across its face which makes the indications visible from any position in front of the board.

These indicators are arranged for mounting on 2-inch panels, but can be used on 1¼-inch and 1½-inch boards by the addition of an adapter.

A 125 or 140-volt candelabra screw-base lamp should be used. For control voltages over 140, the 140-volt lamp should be used with suitable resistor.

Control Relays.—*Control relays* are interposed between the contacts of a main relay or the contacts of a control switch and the apparatus to be controlled, when the current required to operate the apparatus exceeds the current-carrying or interrupting capacity of the main relay or control switch contacts.

Control relays are thus frequently required for the closing-coil circuits of electrically operated carbon and oil circuit breakers. In general, the tripping-coil circuits of circuit breakers do not require sufficient current to make necessary the use of control relays.

Operation.—The operating coil for the control relay is connected directly across the control circuit by the closing of the control switch, causing the control relay to close, connecting the circuit-breaker closing coil across the line.

Control relays are given a maximum current and voltage rating based on intermittent operation. They will give satisfactory service for intermittent duty, namely, with power impressed thereon for not more than 10 seconds out of every 60; this is the condition found under usual operating requirements.

Construction.—These control relays are an adaptation of the well known "contactor type" of switch used most extensively for industrial motor control.

The contacts, which have ample overload capacity, are pressed firmly together with a self-cleaning action.

Flexible copper shunts carry the current from the moving contact to the lower terminal of the relay. No current passes through pins, springs, or bearing surfaces. The top contact is stationary and, therefore, requires no shunt.

Blowout coils are used on all switches. The blowout coils and arcing horns are very efficient in operation, the blowout coils being of special design to handle the highly inductive control circuit. The arc is distributed over a relatively large area as soon as formed and is quickly extinguished. Hence it has practically no destructive action.

DISCONNECTING SWITCHES

Knife-type disconnecting switches are used for isolating oil circuit breakers, feeders, etc., or for making various connections that do not have to be opened under load.

In American practice the knife switches for 2500 volts or less are usually mounted directly on a base of soapstone, marble or similar material, while for higher voltages, insulators of various kinds are used to support the switch jaws. Up to 2500 volts these disconnecting switches are made either front connection, or rear connection, or both, while for higher voltages than 25,000 they are almost invariably made front connection only.

For light service, switches with petticoat insulators are employed, these being made for inverted mounting or for vertical mounting.

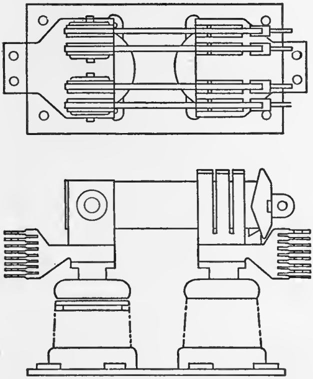


FIG. 11.—Heavy duty disconnecting switch.

For heavy duty, Fig. 11 shows a 4000-ampere, 15,000-volt disconnecting switch. This type is built in capacities of 400 up to 4000 amperes at 7500 and 15,000 volts, and up to 600 amperes for higher voltages up to and including 73,000. In this switch a corrugated conical pillar type insulator is used with the switch part attached to the top of the insulator and the bottom of the insulator attached to a metal base in such a manner that, if an insulator proves defective, it can readily be replaced without the necessity of replacing the balance of the switch. Owing to the severe mechanical stresses set up at the instant of short circuit on systems of large capacity, latches are provided on these disconnecting switches to prevent them being blown open.

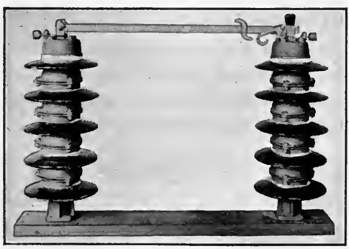


FIG. 12.—Disconnecting switch with built up insulator column.

For voltages of 73,000 and above, it is customary to employ disconnecting switches like Fig. 12, mounted on porcelain posts of the built-up type employing a sufficient number of sections or units to secure the voltage test desired, either for indoor or for outdoor service.

With this type of switch, if an insulator becomes damaged or defective, the units can be readily unbolted from the built-up pillar and replaced by a new section.

Fig. 13 shows a series of switches made for voltages from 22,000 to 110,000. These are mounted on corrugated pillar type insulators that are given a dry test of three times normal voltage. On the larger sizes a truss blade is furnished to secure rigid construction and safety catches are supplied to prevent the switches jarring open. The caps holding the jaw blades are clamped to a wall or other flat structure after they are removed from the wooden template on which the switches are shipped.

The Delta-Star Electric Company have the blades of their disconnecting switches made either plain, for normal light service, or with latches of various types where the short-circuit

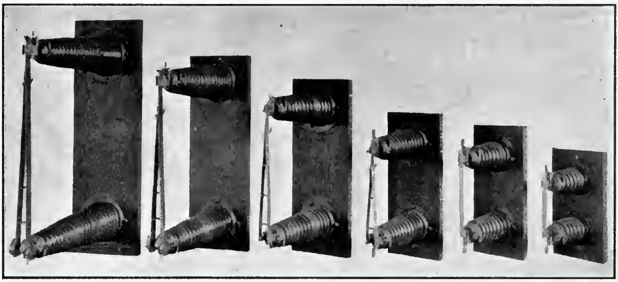


Fig. 13.—Line of General Electric Co. disconnecting switches.

current is such that there is a possibility of the magnetic stresses blowing the switch open if it were not provided with latches.

A very compact type of disconnecting switch for attaching to a bus bar is shown in Fig. 14. In place of cable terminal at the hinge jaw of switch, provision can be made for copper strap connection.

All of the disconnecting switches previously described have been single pole and are operated by means of a hook stick. The various companies make modifications for multipole service mechanically operated as shown in Fig. 15 this being a Delta-Star, three-pole double-throw distant-control switch. Any combination, front or rear connected, can be supplied.

Outdoor high voltage disconnecting switches of one design are built with each pole mounted on three insulators, the end ones carrying break jaws and the line connectors being stationary, the middle one carrying the switch blade rotating in such a way as to introduce a double break into the line.

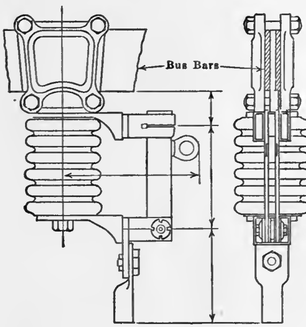


Fig. 14.

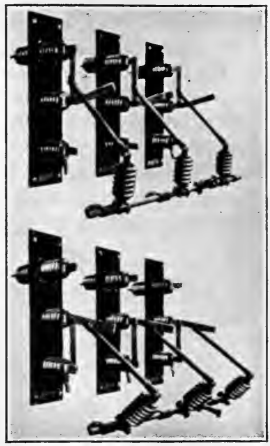


Fig. 15.

Fig. 14.—Delta-Star bus-bar switch.

Fig. 15.—Outdoor high voltage 3 P. D. T. distant control disconnecting switch.

HORN-BREAK SWITCHES

Where it is necessary to open up a high tension outdoor line with power on or when supplying the charging current for a long transmission line, it is necessary to provide arcing horns for the switches, if oil breakers are not employed. These horn-break switches have been made by various builders.

Fig. 16 shows a 50-K.V. horn-gap switch made in single-pole units but arranged so that any number of poles can be mechanically interconnected by means of an adjustable bar and operated from a single operating handle. The main contacts are protected from all burning by the auxiliary arcing horns which make contact before the main contact is closed, and which break away after the main contact is opened. The main contact itself is completely covered by a sleet hood and protected from burning by the auxiliary arcing horn.

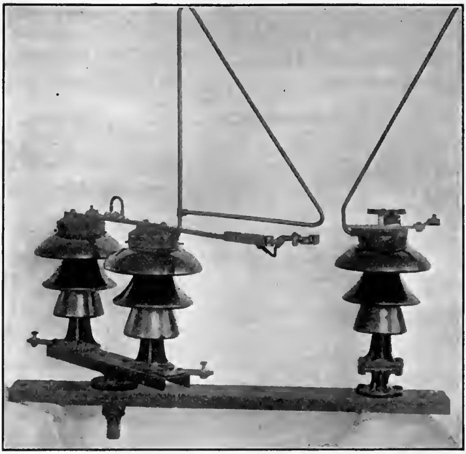


FIG. 16.—R. & I. E. Co. horn-gap switch 50-K.V. single break.

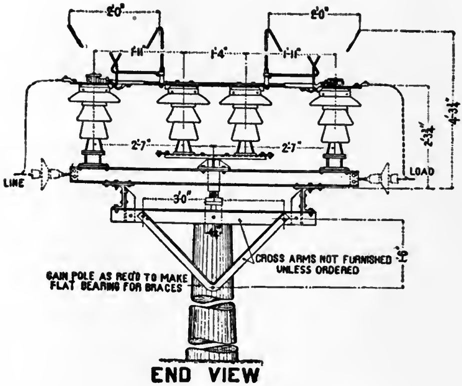


FIG. 17.—Horn-gap switch 70-K.V. double break.

For 70-K.V. service these switches as shown in Fig. 17 are made double break in order to obtain the proper gaps in the line. These switches are intended primarily for mounting on a pole top or a structure with the insulators in the vertical position and the switch arm swinging around on a horizontal plane.

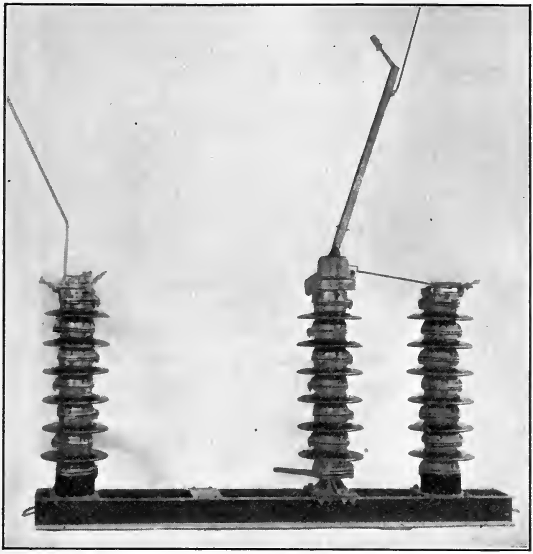


Fig. 18.—R. & I. E. Co. horn-gap switch 120-K.V. vertical break.

For still higher voltages a switch of the type shown in Fig. 18 is utilized. This switch is designed for 120-K.V. service, and while the porcelain pillars are mounted in a vertical position, the switch arm is so arranged as to swing open in a vertical plane instead of a horizontal one.

Where it is desired to obtain automatic protection for a substation or sectionalizing of a line at a moderate cost, an automatic attachment can be added to these horn-gap switches.

The insulator which carries the solenoid trip is mounted in a bearing, and is capable of rotation through a small angle under the torsion of a spring. The trip coil is energized by the main line current. On overload, the plunger in the trip coil magnet releases the latch allowing the insulator to swing by force of the spring. This motion moves a trip rod which releases a main latch, allowing the 3 poles of the switch to open simultaneously. The switch automatically resets by bringing the operating handle to the open position. The switch cannot be held closed on an overload, or on a short circuit.

Modification of this series trip mechanism can be applied to the double-break or the vertical-break horn-type switch.

CHAPTER II

AUTOMATIC PROTECTION AND FUSES

GENERAL FEATURES

One of the most important features of switch gear is the automatic protection secured by means of fuses, circuit breakers or similar devices which guard the various circuits against the trouble that may arise from overloads or any other condition apt to cause damage.

A constant potential generator tends to maintain its voltage independent of the amount of current it may be developing. With a D.C. generator, unless this current is limited by some automatic device, the excessive current is very apt to damage the armature and particularly the commutator, so automatic protection is usually furnished to prevent the current in a D.C. generator reaching a value apt to damage it.

Exciter and Field Circuits.—It has become standard practice, however, not to supply automatic protection, such as fuses or circuit breakers, in exciter and field circuits, as the sudden opening of the field circuits of the A.C. generators, due to the operation of a fuse or breaker in the field or exciter circuit, might cause far greater damage due to puncturing the insulation of the A.C. generator than would arise from the overloading or even short-circuiting of an exciter. In some cases fuses are furnished in exciter circuits of two or three times the normal capacity of the machine so that no ordinary overload could cause them to blow while a certain amount of protection will be afforded to the exciter against a dead short circuit.

Where the exciters also supply current for station service automatic protection is sometimes supplied that will cut off the station circuits in case of trouble while leaving the exciter connected to the field bus. Where exciters are used in parallel with a battery and in certain other conditions, reverse-current circuit breakers are supplied in the exciter circuit that will open only when the exciter tends to draw power from the bus bars instead of delivering power to them.

A.C. Generators.—With the exception of some generator panels where fuses or breakers are furnished for the protection of a line fed directly from the machine or of feeders run from the A.C. bus bars without other protection, it is customary to omit any fuses, circuit breakers, or other automatic devices in the armature circuits of the A.C. generators as most machines have sufficient armature reaction to enable them to stand short circuits for a short time without damage to themselves. In other words, no protection is needed for a moderate size A.C. generator with fairly high armature reaction.

With some very large machines of low armature reaction or important installations it is sometimes advisable to use a circuit breaker in the generator circuit with a reverse-current time limit relay, but such cases are usually special and form an exception to the general rule.

Differential Protection.—More recently a scheme of differential protection for large generators has become almost universal, utilizing current transformers in each end of each phase winding of a generator, *i.e.*, at the neutral as well as in the outgoing leads and balancing these against each other. For all conditions of overload or external short circuit the system is non-automatic, but any internal short circuit or ground in the generator will cause an unbalancing in the relay circuit causing the tripping of the generator breaker and field switch.

Converters.—For the protection of synchronous converters or motor-generator sets, the rules applied to D.C. generators apply for the direct-current end of the machine. The circuit breaker, which is almost invariably used in the D.C. circuit, is usually provided with a low voltage release coil in addition to the usual overload coil, and this release coil may be short-circuited by a reverse-current relay if it is desired to guard against the machine taking in D.C. current and delivering A.C. current. The speed limit device, when furnished, usually short-circuits this low voltage release coil to cut off the D.C. current in case of excessive speed.

For the A.C. end of a converter fed directly from a low tension generator or bus, automatic protection is usually furnished. When fed from its own transformer or bank of transformers, the automatic protection is usually supplied on the high tension side of the transformers and no automatic devices are used between the A.C. end of the converter and the low tension transformer circuit.

Circuit Protection.—In a generating station with A.C. generators supplying power to a low tension bus, which in turn furnishes current to step up transformers feeding a high tension bus and outgoing transmission lines, it is customary as previously explained to make the generator breakers non-automatic. Those for the low tension side of the transformers are made overload automatic, those for the high tension side of the transformers non-automatic, those for the outgoing lines automatic and any tie or junction breakers in the bus bars non-automatic. In a step down transformer station the same scheme is followed except that the high tension transformer breaker is automatic and the low tension non-automatic. Occasionally with transformers differential relay devices are used, operated from current transformers in the high tension and low tension circuit in such a manner that as long as the ratio of transformation remained practically constant, the breakers would be non-automatic but if any internal trouble in the transformer modified this ratio of transformation, the differential relay would act and both high tension and low tension breakers would be tripped out.

FUSES

Fuses, open link, at first were small copper wires and their great drawback was the high melting point of the copper and the consequent heat of the molten metal dropping from the fuse and the formation of copper globules. To reduce the heat of the molten metal, lead, tin, or some alloy with low fusing point was used, but such fuses had the drawback of being too soft and easily damaged when tightening up the contact nuts. The next step was to use alloy fuses with copper tips and these are still used to some extent.

As the price of aluminum was reduced this material was used largely for fuses as it has a high conductivity reducing the amount of metal fused, a fairly low melting point and almost complete vaporization of the metal fused. By using wide strips of aluminum cut to form two or more bridges, fairly reliable open fuses can be made up to 1200 amperes. An ordinary metal strip exposed to draughts of various kinds is apt to be very erratic in its behavior as a fuse and is apt to throw molten metal when it blows. These defects in the behavior of open fuses finally led to various devices to remedy these troubles—one being the enclosure of the fuse in a suitable receptacle or tube.

Fuses, Expulsion.—It was found that the fuses for 1100-and 2200-volt service were decidedly dangerous unless properly covered up, and if they were placed in an airtight box they were apt to rupture the box by the explosion of the gases formed when the fuses blew. It, therefore, became necessary to provide a vent for the gases and the natural development was to place the vent in such a position that the gases in expanding caused a strong draught through the vent and this was used for blowing out the arc. This resulted in the expulsion type of fuse holders.

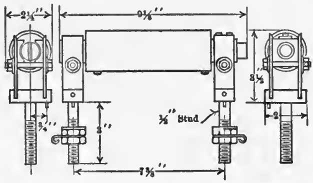


Fig. 19.—Typical expulsion fuse and block.

The earliest designs of this type comprised a removable fuse holder of lignum vitæ or similar tough close-grained wood, equipped with terminals which fit into suitable blocks. Later types have the fuse placed in a fibre tube and arranged to blow out through one end like a bomb.

Fig. 19 shows a typical expulsion type fuse block for indoor service up to 7500 volts in capacities up to 100 amperes and similar fuse holders are available up to 25,000 volts.

These fuse blocks are made especially for opening the circuit in the event of sudden and severe overloads or short circuits, but they are also entirely suitable for the protection of circuits in the case of gradually increasing overloads if the fuse wire is inserted in asbestos sleeving.

The fuse tube is readily removable from the contact clips and the fuse wire easily inserted therein, making the re-fusing a very simple matter. These fuse blocks will operate satisfactorily on any circuits within their interrupting capacity, which is approximately 1000 amperes at 7500 volts when used one per wire and proportionately greater or less at other lower or higher voltages.

The fuse tube is hollow and one end is left open, so that when the fuse blows, the metallic vapors are expelled from the tube through the open end and successfully extinguish any arc incident to the blowing of the fuse. Before being inserted in the fuse tube the fuse wire should be enclosed in asbestos sleeving. The asbestos sleeving prevents the gradual charring of the inside of the fuse tube by the overheated fuse and thereby eventually lengthens the life or prevents burning out of the fuse tube. The open end of the fuse tube extends beyond the contact jaw so that all danger of the expelled vapors coming in contact with the metallic portion of the block is eliminated.

Enclosed fuse consists essentially of a fusible wire, strip or sets of wires and strips enclosed within a tube, usually of fibre, filled with a material to exclude the air and to facilitate the opening of the circuit when the fuse blows by absorbing the gases formed and chilling out the arc. Suitable terminals are provided so that the fuse may be mounted in a fuse block.

N.E.C. Fuses.—When enclosed fuses were first put on the market each manufacturer developed his own designs of terminals and used his own spacings so that there was no uniformity

FIG. 20.—Enclosed fuse with ferrule contacts.

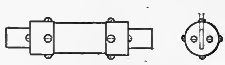


FIG. 21.—Enclosed fuse with blade contacts.

and the fuse of one make could not be used in the fuse holder of another manufacturer. To avoid this confusion the representatives of the fuse builders and the National Board of Fire Underwriters finally adopted certain standard dimensions and types of contacts for various sizes and voltages. Up to 60 amperes ferrule type contacts are used as shown in Fig. 20, and from 61 amperes to 600, knife blade contacts are employed as shown in Fig. 21. One set of dimensions are used for fuses up to 250 volts and another for fuses up to 600 volts. Fuses that correspond to the accepted dimensions and that meet other requirements agreed on are known as National Electrical Code (N.E.C.) fuses and are perfectly interchangeable.

Limits.—On large systems the circuit characteristics should be such as to limit the maximum overload power passing through the fuse to approximately 10,000 kilovolt-amperes. Circuit breakers are recommended instead of enclosed fuses where the rated capacity of the generators supplying the circuit on which they are directly installed exceeds 2000 kilovolt-amperes, as fuses are not suitable for such circuits.

Indicators.—Each fuse is provided with a simple but reliable device which indicates whether the fuse has blown or is still intact. This indicator is in plain view so that the condition of the fuse can be determined at a glance.

Fuse blocks and fuse holders for enclosed cartridge fuses for voltages up to 25,000, front and rear connected, are used for mounting on the wall or on switchboard panels and are rated according to the ampere and voltage capacities of standard cartridge fuses with which they are designed to be used, and the ratings apply to either direct or alternating current.

The 250-*volt and* 600-*volt* fuse blocks have the National Electrical Code standard dimensions and will receive any cartridge fuses of corresponding ampere capacities conforming thereto.

Fuse blocks for glass cartridge fuses for capacities up to 2 amperes, 250 volts, single, two and three-pole use a small glass-tube fuse of 2-amperes capacity. They are used principally for the protection of instruments connected directly to the line without transformers and in the secondary circuit of instrument transformers.

The complete block consists of fuse clips of the ferrule type mounted on porcelain blocks with barriers on the outside edges and, with the two and three-pole blocks, between poles. They are made for mounting on the wall or in the rear of panels and are front connected.

Switchboard-type fuse blocks as shown in Fig. 22 are made for switchboard use where it is desired to replace the fuse from the front of the panel. The standard enclosed fuse is inserted in the clip in the plug and the plug is then screwed into the receptacle until the fuse enters the inner contacts. These fuse blocks are for $1\frac{1}{4}$-inch, $1\frac{1}{2}$-inch and 2-inch panels.

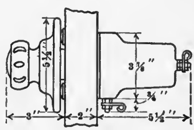


Fig. 22.—Switchboard type fuse block.

Fuse blocks with porcelain insulators and cast-iron or sheet-steel bases, wall mounting type, are used for the protection of switchboard mounting and other voltage transformers of small capacity for voltages up to 25,000 maximum. They can, however, be used on any circuit up to their rated capacity.

Transformer Fuses.—When the A.C. system was developed with distributing transformers mounted on houses or poles and exposed to the weather, it became necessary to develop suitable fuse protection for them and various types of fuse blocks and fuse holders were designed. The usual form for moderate capacity transformers on 7500-volt circuits was a porcelain fuse holder carrying a small piece of fuse wire placed in deeply recessed grooves in the fuse holder but as voltages increased, it became necessary to go to another type.

Fig. 23 shows a 25,000-volt combination fuse holder and disconnecting switch developed for outdoor service and this fuse holder, of the expulsion type, can readily be made suitable for higher voltages by using larger insulators and increasing the dimensions of the fuse tube.

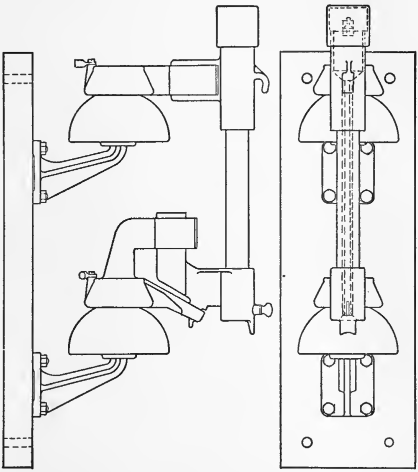


FIG. 23.—Disconnecting switch type of expulsion fuse.

S. & C. Fuse.—Another type of fuse, known as "The S. & C. Fuse" but sometimes called "Carbon Tetrachloride Fuse" has been developed by Schweitzer & Conrad, Inc. These have been used outdoors and indoors for voltages up to 115,000 and in current capacities up to 400 amperes. The fuse is located in a glass tube that contains a spiral spring, the lower end of which is connected to the bottom ferrule. The upper end of the spring connects to the fuse wire passing through a cork, the upper end of the fuse wire being connected to a short wire soldered to the cap on the top ferrule. At the top of the spiral spring and just below the cork is a funnel-shaped liquid director. The glass tube is filled with a noninflammable liquid of extremely high dielectric strength, having none of the objectionable characteristics of oil. This liquid is not only not an oil, and therefore noninflammable, but is one of the most effective fire extinguishing liquids known.

Operation.—The melting of the fuse wire releases the spiral spring which contracts instantaneously, drawing the fuse wire down towards the bottom of the tube and thus introducing a very large gap. Simultaneously with the introduction of this gap, the liquid extinguishes the arc and interrupts the current flow, the rapidity of its action being accelerated by the liquid director which is drawn down with the spring and so forces the liquid directly on to the moving terminal.

Since the dielectric strength of the liquid is about 250,000 volts per inch, the gap between the top ferrule and the top end of the submerged spring gives an enormous factor of safety. The dimensions of the glass tube and other parts vary, depending upon the ampere capacity and voltage rating of the fuse. According to tests, this fuse operated in less than one-fifth of the time required by oil circuit breakers; the longest time required to open the circuit was 0.03 seconds. This is remarkable when compared to the quickest operating oil circuit breaker which takes at least 4 cycles on 25-cycle current, or a minimum of 0.16 seconds.

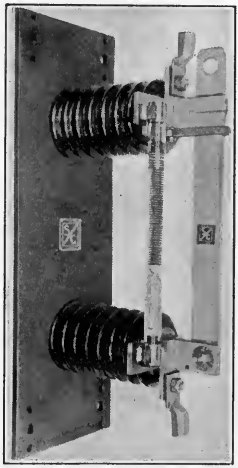


FIG. 24.—Schweitzer-Conrad shunted switch with carbon tetra-chloride fuse.

Weatherproof Cut-out.—For use as a weatherproof primary cut-out, a special holder of moulded insulating material is provided. The S. & C. Fuse attached to a handle of the same material as the holder, fits into the holder in such a manner as to make a bayonet type plug switch.

Fused Switch.—The fused switch is furnished for those installations where it is desired to install a combination disconnecting switch and fuse mounting, but where the space is so limited that the regular types cannot be used.

The middle portion of the disconnecting blade is replaced by two pieces of Bakelized insulating material, and the fuse is mounted across this insulated gap so that the current is carried through the fuse. The fuse is mounted in regular fuse clips with the regular retaining bales, so that no difficulty is encountered in the opening and closing of the blade.

Shunted Switch (Fig. 24).—Another adaptation of this type of fuse consists essentially of a disconnect shunted by a fuse of low amperage and provided with a lock, so that the disconnect cannot be opened unless the fuse is in place. If the disconnect is opened when it is carrying current, the current is shunted through the fuse where it is interrupted when the fuse blows due to the current being above the rated current of the fuse.

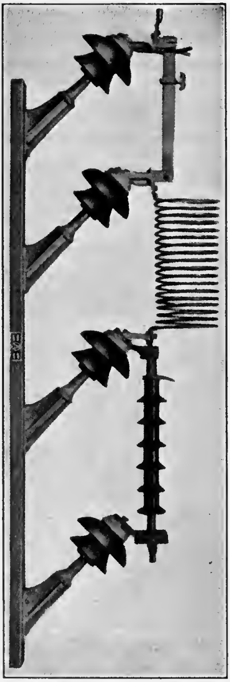


FIG. 25.—Delta-Star outdoor fuse arrangement.

Mountings.—A number of types of mountings for S. & C. fuses have been developed by Schweitzer & Conrad, Inc. and the Delta-Star Electric Company. Various types are furnished for both indoor and outdoor service, including many combinations for installing the fuses with choke coils, disconnecting switches, etc. For outdoor service, the fuse is mounted on a pair of petticoat insulators mounted horizontally, vertically, or at an angle of 45 degrees. Similar outdoor arrangements, utilizing General Electric Expulsion Fuses are shown in Fig. 25.

The fuse holder for expulsion type fuses is made of porcelain, designed to give high mechanical strength. At each end are placed contact elements, which engage the stationary contacts of the mounting. The upper end is closed, the lower end open.

The fuse wire is passed through the holder and connected to the brass contacts at both ends. At the upper or closed end of the holder, the fuse cross-section is reduced insuring that the fuse melts at this point. Melting of the fuse generates gas, which expands and explosively forces the arc downward, expelling it through the lower or open end of the holder, thus rupturing the circuit.

Fused Breaker.—The fused type circuit breaker is a modification of the carbon circuit breaker that has been used to quite a large extent in connection with moderate capacity high voltage circuits.

This circuit breaker is designed for potentials from 6000 to 60,000 volts. The circuit breaker consists of two hardwood poles, one being longer than the other, mounted upon porcelain petticoat insulators, to which are secured the terminals for the main leads or wires. The wood poles are connected by a hinge, so that their extremities are in line at the upper end. On the upper end of each pole is mounted a copper sleeve supporting a round carbon contact block with a hole through its center. The longer pole is provided with spring jaws or clips so that it may be quickly and easily attached to, or detached from, the terminals on the insulators. The short pole has a flexible wire running through its interior; this wire is connected to the copper sleeve at the upper end of the short pole and to the lower clip terminal on the long pole. The sleeve at the upper end of the long pole is connected to the upper clip terminal. These connections make the sleeves at the upper ends of the two poles the terminals of the apparatus.

Early Type.—In the earliest type of fused circuit breaker the fuse of aluminum wire was exposed in the air and it was necessary to allow ample space above it for the arc to rise and dissipate itself. For the lower voltages the marble base was depended on for insulation while for the higher voltages the marble base was mounted on insulators. These fused switches were used in considerable number in some of the earlier Interurban Railway Substations filling the demand for a moderate priced high voltage overload breaker to give automatic protection on the high tension side of the transformers.

Latest Type.—The latest modification of this device as shown in Fig. 26 has the marble base replaced by petticoat insulators mounted on long pins.

Construction.—The fused type circuit breaker is lightly, yet strongly constructed. The circuit breaker mechanism consists of a long hardwood pole on which is mounted a movable arm consisting of a reinforced fuse tube. At the bottom of the fuse tube is a brass expulsion chamber which is connected to the lower terminal of the breaker by a flexible copper shunt. Attached to the top of the pole and forming the upper circuit-breaker terminal there is a brass bracket, with a groove along its top, which supports the fuse, and a wing nut to hold the end of the fuse when the breaker is closed. The fuse passes from the wing nut over the bracket and down through the fuse tube to the expulsion chamber where it is attached to the screw-plug terminal shown in the end of the expulsion chamber.

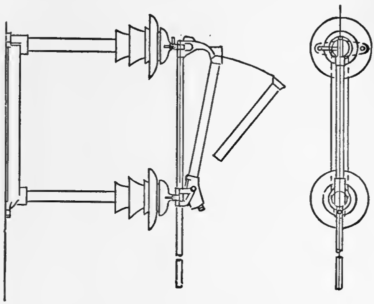


Fig. 26.—Fused circuit breaker.

S. & C. Breaker.—Still another type of high voltage breaker based on the same principles as the S. & C. Fuse is made by Schweitzer & Conrad, Inc. and is shown in section in Fig. 27.

Construction.—The switch consists essentially of a moving contact mounted on the end of a spring actuated operating rod, and of a stationary contact mounted in the base of the circuit breaker, and so arranged that when the moving contact reaches the closed position, the two contacts engage each other. The current is conveyed to the moving contact through flexible copper connections so that the current carried by the spring is negligible. Mounted on the end of the operating rod and next to the moving contact is the liquid director, a funnel-shaped arrangement that forces

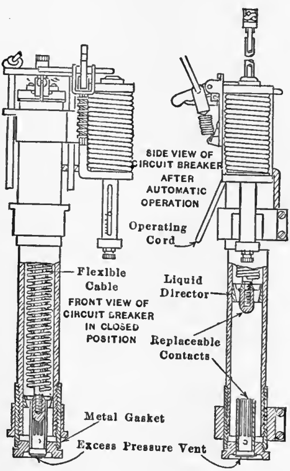


Fig. 27.—S. & C. high voltage breaker.

a powerful stream of the liquid onto the moving contact as it recedes through the liquid when opening. Immediately under the stationary contact is the excess pressure vent which opens when the pressure in the main tube becomes abnormally high, due to the rupturing of very heavy short circuits. This vent, as well as the two contacts, is very easily replaced.

Latching Arrangement.—The operating rod which carries the moving contact extends through the top of the circuit breaker and is provided with a cross-bar to which the operating ropes or other mechanism are attached. On top of the switch is a latching arrangement which holds the circuit breaker in the closed position. This latch is released by a small lever projecting to the front which makes it convenient for any method of tripping that may be chosen.

Overload Relay.—Mounted on top of the circuit breaker is the series relay which provides the automatic overload feature. This simple plunger type relay is calibrated for several values above and below the normal operating current and will cause the circuit breaker to open whenever the current equals or exceeds the relay setting.

The liquid used in these circuit breakers, is a noninflammable liquid of a very high dielectric strength. It is not only noninflammable but it is a fire extinguisher, and therefore has none of the objectionable characteristics of oil. It has many of the characteristics of Carbon Tetrachloride, but the boiling point is very much higher than that of Carbon Tetrachloride. It is necessary to use this liquid having a higher boiling point as the circuit breakers are not hermetically sealed because of the necessity for some clearance around the operating rod where it enters at the top.

CHAPTER III

CARBON BREAKERS

Historical.—The previous chapter on automatic protection gave an idea of the various cases where it is desirable to protect circuits by means of fuses or circuit breakers. Fuses were among the earliest means provided for securing automatic protection, particularly in D.C. lighting plants. When the direct-current railway system was started it was soon found that with 500 volts or more, and the fairly large currents that were to be handled, that fuse protection was not satisfactory and automatic circuit breakers of different kinds were designed. The earliest circuit breakers were practically knife switches with automatic features, but the rapid burning away of the contacts necessitated some means of reducing the vicious arcs that occurred when opening the circuit.

Carbon Breakers.—One of the earliest designs that has stood the test of time is a circuit breaker with auxiliary carbon contacts. These auxiliary contacts remain closed until the main contacts open and the carbons take the final arc. The fairly high resistance of the carbon vapor in the arc and the fact that the vaporized carbon was completely burned up aided in the satisfactory operation of this device.

The principal demand for circuit breakers is to have them open the circuit when the current reaches a certain predetermined value, and breakers are designed with this end in view. They are also built for underload conditions to open on minimum current, for overvoltage to open when the voltage exceeds a certain amount, for undervoltage to open when the voltage falls below a certain minimum value and for reversal when the current flows through the breaker in the opposite direction from that which was intended. It is, of course, possible to combine these various features of overload, underload, reversal, etc., in one and the same breaker.

Owing to the impossibility of illustrating all capacities and types of carbon break circuit breakers, the general features of carbon break circuit breakers are considered in considerable detail and the distinctive features of different makes are illustrated by examples of a few representative ones.

Space Required.—The modern tendency is to economize in space wherever possible. So much apparatus must be installed in so little space that it is often necessary to choose the smaller of two similar pieces of apparatus. A circuit breaker that gives the required performance, and at the same time is small, often means considerable saving in space.

Desirable Features.—It is essential that there be good contact between the current-carrying parts of a breaker in order to obtain the maximum current rating. Poor contact produces local heating. A millivolt drop as low as possible is desirable in a circuit breaker. This is best obtained by having perfect contacts and current-carrying parts of ample size.

The carrying capacity of a breaker depends on the contact and conductivity losses, the degree of ventilation, and the allowable temperature rise. The last point is of special significance. In comparing the capacities of different breakers, the allowable temperature rise must be taken into account in order to provide the same basis of rating for each breaker; otherwise the ratings will not afford a true comparison of capacities.

In order that a circuit breaker may give the best service it must be easy closing. To obtain good service on the system, the breaker must be "positive holding," that is, when it is closed, it must stay closed until tripped by one of its tripping devices. Vibration or stray fields should not open it. When a breaker opens, whether tripped by the operator, by overload, or by any other means, it is absolutely essential that its release be positive and quick so that it breaks the circuit instantly. It should never open sluggishly.

Dust and other foreign particles are liable to lodge on the contacts of carbon circuit breakers. Repeated openings of the breaker under load will burn the contacts slightly, making them rough. In order that the dust may be cleaned off and that the slightly rough surface may be kept smooth, a breaker should have a self-cleaning action, that is, its contacts should be so arranged that there is a slight wiping action between them when they are being opened and closed.

A circuit breaker should be easily adjusted, but when set, its adjustment should be permanent until changed by the operator.

A circuit breaker must be reliable. It should have positive operation under all conditions. Better have none on the line at all than have one that cannot be depended upon.

Temperature.—The current-carrying parts adjacent to the contact surfaces of carbon circuit breakers should carry their full-rated current continuously with a maximum temperature rise of either 20 degrees or 30 degrees Centigrade, above the temperature of the surrounding atmosphere.

The 20-degree rise basis is recommended when the maximum temperature of the air where the breaker is located may approximate 40 degrees Centigrade and the load is practically continuous as on generator, converter, or transformer circuits.

The 30-degree rise basis is recommended where the maximum temperature of the air where the breaker is located may approximate 30 degrees Centigrade or less, or the load is intermittent, as on feeder circuits.

The insulated coils of most carbon circuit breakers will carry their full-rated current continuously with a maximum temperature rise of 50 degrees Centigrade above the temperature of the surrounding atmosphere.

Current Ratings.—The current ratings shown for all carbon circuit breakers listed in makers' catalogues are maximum based on the allowable temperature rise that is reached after a continuous run of approximately one hour or more at the rated current. Inasmuch as a circuit breaker reaches its final temperature quickly with steady current load, it is necessarily a maximum rated device. In selecting a breaker, it is, therefore, recommended that the rated capacity should be at least as great as the maximum rated one-hour (or more) overload current of the apparatus that the breaker will be required to control. Owing to the "skin-effect" and eddy-current heating in alternating-current conductors, a circuit breaker with the same rise in temperature has a lower alternating-current rating than direct-current rating. Also, on 25-cycle service a circuit breaker above 300-ampere rating will carry continuously considerably more than its 60-cycle rating.

Interrupting Capacity.—While the interrupting capacities of most of the high-grade carbon breakers meet the requirements of the National Electrical Code, and in certain cases are much greater, it should be noted that the smaller types of various manufacturers should not be connected too closely to apparatus or bus bars capable of delivering larger amounts of power than specified by the Code. The relatively small wires ordinarily used to connect these lower-capacity circuit breakers with sources of power should be sufficient to introduce enough resistance to limit the current that can be drawn through the breaker under short-circuit conditions to the amount specified by the Code.

Intricate mechanism in a circuit breaker means endless trouble. Simplicity should be looked for in every part.

Accidents that cannot be foreseen are always liable to happen, and repairs must be made sometimes to the best breaker. A circuit breaker should be so designed as to facilitate repairing, and thus cause the least possible delay in putting it back in service.

Distinctive features of the best types of carbon circuit breakers are: exceptional ruggedness and neatness of appearance; simplicity of construction, operation, and installation; few parts, all easily accessible, and those parts likely to require replacement, easily renewable; great compactness, thus saving in space; long rigid carbon arms, giving long break of arcing members; current-carrying parts of ample size so that no portion of breaker will exceed guaranteed temperature rise; main moving contacts are laminated copper brushes, self-wiping or self-cleaning; auxiliary contacts in addition to main contacts; self-aligning, self-cleaning carbon contacts; contact pressure adjustable; low resistance from main contacts to carbon-arcing contacts; small millivolt contact drop; very simple toggle mechanism; all breakers trip easily, quickly and positively; auxiliary tripping and signalling attachments are easily applied.

Construction.—In high-grade carbon circuit breakers special attention has been given the problem of keeping the size of breakers down to a minimum for the required performance. The construction is such that the best possible ventilation is secured, the object being to obtain the maximum radiating surface on all current-carrying parts, and thus insure a breaker of the highest current-carrying capacity for its size.

On the mechanically operated breakers, the closing mechanism consists of the operating handle and the toggle mechanism connecting the handle lever and the main contact arm. On the electrically operated breakers, the closing is usually effected by means of a direct-current solenoid mounted below the main mechanism. The solenoid plunger is connected to the closing mechanism in such a way that when current flows through the solenoid and the plunger is drawn into the solenoid, the main contacts are closed.

The contacts of these breakers are held closed automatically by a trigger or latch. The various trip mechanisms are constructed to disengage this latch and permit the breakers to open.

Main Contacts.—All current-carrying contacts are made of copper. The movable element is a laminated brush composed of several strips of copper and makes an end-on, or butt, contact with the fixed element; this gives a relatively large wiping, or self-cleaning contact when the breaker is closed and insures uniform pressure over the entire contact surface. A high contact pressure is obtained because of the form of mechanism between the handle and contacts. This pressure reduces the heating of the contacts to a minimum and secures a low contact-resistance. A means is provided for adjusting this contact pressure and for equalizing the pressure on both ends of the moving element.

The main contact block, or fixed element, and the terminal stud are of two forms: the round threaded form and the slotted-bar or laminated form for laminated connections. In the smaller capacities below 2500 amperes, direct current, they are made up of drawn round or rectangular copper bar stock, electrobrazed to form the terminal stud and contact blocks. In the larger capacities, higher than 2000 amperes, direct current, they are "pressure moulded" of extremely high-conductivity copper, or made with laminated copper bars.

The slotted-bar studs are arranged with slots to take laminations running either vertically or horizontally, or with one stud with vertical and the other stud with horizontal slots, thus allowing the connections to the bus bars to be made in the most convenient manner.

METHODS OF OPERATION

Under average conditions, for simple plants having not over 10,000-ampere 750-volt units, carbon circuit breakers can be mounted directly on the switchboard panel. Where the requirements exceed these, remote-controlled breakers mounted apart from the panel and electrically controlled from the panel by an auxiliary circuit become advisable. For 1500-volt service in capacities up to 2500 amperes the single-pole manually operated remote-control breakers are recommended. Electrically operated remote-controlled breakers are also made for lower capacities for applications where for other reasons it is preferred not to mount the breaker directly on the panel.

Manual Operation.—Manual closing by a handle connected directly to the breaker is the ordinary method of closing carbon circuit breakers. Pulling down on the handle closes the breaker.

Electric Operation.—In the field of power operated carbon circuit breakers the Westinghouse Electric & Manufacturing Company and the General Electric Company adopted as standard the direct-current electrical-solenoid magnet method of closing. The Cutter Company use various other methods, such as motor, hydraulic and pneumatic closing in addition to solenoids.

Solenoid operated carbon circuit breakers of one design are closed by means of a simple cylindrical magnet mounted below the breaker mechanism. The solenoid is equipped with a dash-pot device that takes care of the shock at the end of the closing operation, and yet permits the breaker to close quickly. When the closing switch is thrown, current flows through the solenoid and the plunger is drawn down. This closes the contacts, which are held closed automatically by a latch. The solenoid plunger rises when the closing circuit is opened, so that it will not retard the opening of the breaker when tripped. The breaker is opened by the automatic overload trip or by the shunt-trip attachment mounted at the side of the breaker mechanism. The breakers can be tripped manually by pushing up on the operating handle or back on the insulated trip handle near the bottom of the breaker.

Standard closing coils are wound for direct current. Direct-current mechanisms, besides being simpler in construction, more reliable in operation, and more easily kept in repair, are much more economical of space and power than alternating-current mechanisms. Alternating-current shunts and current transformer trip coils are available in special cases.

The closing and tripping mechanisms are operated by a control switch with or without a control relay in the operating circuit, and usually with signal lamps. The electric operating mechanism has a small double-throw switch to operate the signal lamps and to open the shunt-trip coil circuit when the circuit breaker has opened.

Acceleration.—On account of the reaction of the laminated moving contact members, no separate means of accelerating the breaker to its open position are necessary. The laminated members, which act as powerful springs, the toggle-lever springs, the secondary-contact springs, and the carbon-arm springs, all serve to accelerate the opening of the breaker.

In general, carbon circuit breakers are made for either panel or separate mounting. For separate mounting they are usually furnished mounted on a slate base with black marine finish.

Non-automatic breakers are simply switches capable of opening overloads, but opened and closed only at the desire of the operator. They can be made automatic through relays operating on a shunt-trip coil.

Tripping Methods.—All standard overload-trip carbon circuit breakers are plain-automatic, that is, when closed with an overload on the line, they will remain closed as long as the closing handle is held down or the closing coil is energized, but will not remain closed when the handle is released or the closing circuit is opened.

Full-automatic overload-trip breakers trip free of the handle so that they cannot be held closed on a short circuit or overload.

All standard overload-trip carbon breakers are arranged for direct acting (series) tripping without relays. In some cases breakers used on alternating-current circuits are supplied for transformer tripping. Breakers used on alternating-current circuits and equipped with shunt-trip coils can be made transformer-trip through relays acting on the shunt-trip coils.

Calibration.—The standard range of calibration for automatic overload-trip varies with different makes. A typical range is from 80 to 160 per cent. of the 30-degree rise ampere rating. Breakers can readily be set to trip at any point within their range. Calibration higher than standard can be furnished in most cases.

SPECIAL ATTACHMENTS

Shunt-trip Attachment.—The shunt-trip attachment enables the breaker to be tripped electrically from some distant point. A direct-current shunt-trip mechanism is included as standard with each electrically operated breaker and can be supplied as an accessory on almost all manually operated breakers. If the circuit breaker is not arranged to cut out the shunt-trip circuit, signal contacts should be provided to do this when the circuit breaker trips, as the tripping coils are designed for intermittent service only. The automatic undervoltage-trip attachment when supplied with a suitable resistor, can be used as a shunt-trip mechanism by momentarily short-circuiting the coil.

Inverse Time Limit Attachment.—An inverse time limit dash-pot with an adjustable time feature can be used with some breakers. This attachment will cause the breaker to trip almost instantly on heavy overload and much more slowly on light overloads, giving the circuit on light overload the chance to clear the trouble before the breaker trips.

Automatic Undervoltage-trip Attachment.—The undervoltage-trip attachment is used to trip the breaker when the line voltage fails or falls approximately 50 per cent. or more under the rated normal voltage. It is of particular advantage in automatically disconnecting a motor from the circuit at the time of temporary interruption of the supply circuit, for should the motor come to rest and still be connected to the line it would be subjected to full voltage upon the power being restored. The automatic undervoltage-trip attachments for carbon circuit breakers are reset by hand or automatically on the opening of the breakers according to requirements.

Only one undervoltage attachment is necessary with multipole breakers. No additional protection is afforded by the use of a coil across each phase of a 2-phase or 3-phase circuit for the reason that the motors, when the voltage of one phase fails, will run single phase and feed back into the idle phase, thus preventing the undervoltage device from acting; but the resulting overload on the working phase, due to the entire load being on that phase, will trip a properly set breaker.

The undervoltage-trip attachment, if supplied with suitable resistor, can be used also as a shunt-trip attachment by momentarily short-circuiting the coil.

Automatic Reverse-current Trip Attachment.—This attachment is particularly applicable to storage-battery charging, or the operation of direct-current generators or synchronous converters in parallel, its function being to disconnect the generator from the bus whenever the current reverses due to any cause, as for example, rise in battery voltage, drop in generator voltage, or stopping of the prime mover. It is not affected by an overload in the normal direction, and can be applied to non-automatic breakers where the reverse-current protection only is desired.

The automatic reverse-current trip attachment automatically resets itself after the tripping operation and is prompt and reliable in its action. Two windings are provided, one shunt and the other series, the former having a shunt cut-out which automatically opens the circuit when the breaker trips. If desired, the tripping current may be obtained from a circuit other than that in which the circuit breaker is connected.

The tripping range can be easily adjusted. If the shunt coil is supplied with normal voltage, the Westinghouse attachment can be set to trip the breaker at any current value from about 5 per cent. of normal rating in the positive direction to 25 per cent. of normal rating in the negative or reverse direction. The amperes required to trip the breaker will be affected only slightly by small changes in voltage.

Automatic Overvoltage-trip Attachment.—The automatic overvoltage-trip attachment is used principally in connection with storage-battery charging, where it is desired to cut off the current supply when the battery becomes fully charged. It may, however, be used in any alternating-current or direct-current circuit which it is desired to open automatically in case of either moderate or abnormal rise in voltage.

Automatic Underload-trip Attachment.—The automatic underload-trip attachment is principally used on storage-battery charging circuits. When the charging current decreases to a certain predetermined value, the breaker is tripped; the circuit is thus opened and the chance of current flowing back from the battery to the generator and causing trouble is thus avoided. For this application the attachment is generally set to trip at 10 per cent. of normal load, but the standard attachments can be set to trip at any point from 10 to 25 per cent. The automatic underload-trip attachments are reset by hand or automatically by the opening of the breaker, according to service desired.

Signal Contacts.—For use as shunt-trip cut-outs and in operating signal lamps, a single-pole double-throw plunger switch that automatically closes one signal circuit when the breaker is closed and another when it is open is supplied. This attachment is fastened to the panel and is operated by an insulated rod actuated from the moving main-contact brush of the breaker. It has a switching capacity carrying from 10 amperes at 125 volts to 1 ampere at 750 volts.

Bell Alarm Contacts.—For this service any small double-throw single-pole switch can be used in conjunction with the signal switch above referred to, for indicating by lamps, bells, or other signal, the operation of the breaker. The signal contact switch is connected as a single-pole, double-throw switch and, in conjunction with the single-pole, double-throw, bell alarm cut-out switch, makes the necessary connections to ring a bell or operate a signal when the breaker is in the position opposite that desired by the operator.

Relays.—Where a more reliable time limit is required for selective operation of circuit breakers than can be provided by the type of dashpot described above, protective relays should be used in connection with the circuit-breaker shunt-trip coils. The use of relays in connection with an auxiliary source of direct-current power for tripping obviates the use of overload coils and time limit features on the circuit breaker.

Field-Discharge Contact.—A combined shunt-trip and field-discharge contact is usually supplied with the 2-pole form of breaker for use in connection with exciter generators or as main field switches to large alternating-current generators. In this service the breaker is usually made non-automatic as the excitation should only be interrupted at the will of the operator. Reverse-current trip is sometimes applied to this field-discharge form of breaker when it is used as the exciter-generator main switch or breaker.

Double-arm Attachment.—The double-arm attachment eliminates the necessity for switches in series with a 2-pole single-handle breaker in low capacity and low voltage service and at the same time affords automatic protection to the circuit throughout the closing period. With this arrangement, each pole of the breaker is closed independently and in succession, so that the pole first closed is left free to open while the second or final pole is being thrown in. The breaker being closed, an overload in either positive or negative line, or both, will trip both poles simultaneously.

Trip-free-on-overload Attachment.—The trip-free-on-overload attachment (also known as "full-automatic-overload trip") on a breaker makes it impossible to hold the breaker in a closed position while a continued overload condition or short circuit exists on the line.

Full-automatic or "trip-free" operation, particularly on direct hand controlled carbon breakers, is not recommended for high-capacity circuits or for service of over 250 volts D.C., or 440 volts A.C. Carbon breakers should not be closed on a circuit under heavy load. Another switch should be used to close the circuit, especially under overload; otherwise damage to the secondary and carbon contacts, or injury to the operator, may result.

In order to cover the field of carbon breakers in as complete a manner as the space requirements will permit, typical breakers of most of the important American builders are illustrated and described without attempting to go much into detail regarding any one breaker. A few diagrams are included of special circuit breaker features such as the connections of the "Auto Reclosing Breaker," and the internal connections of a motor operated breaker of the Cutter Company.

List of Makers.—Carbon break circuit breakers have been made by a great number of different manufacturers, but the best known ones are those that have been made by the following American Works:

Automatic Reclosing Circuit Breaker Company, Columbus, O.
Condit Electrical Manufacturing Company, Boston, Mass.
Cutter Company, Philadelphia, Pa.
General Electric Company, Schenectady, N. Y.
Roller Smith Company, Bethlehem, Pa.
Westinghouse Electric & Manufacturing Company, Pittsburgh, Pa.

AUTO RECLOSING CIRCUIT BREAKER

Operation.—The Automatic Reclosing Circuit Breaker is a magnetically operated breaker. There are three coils which govern its action.

First.—The operating coil O, which closes the main contact and holds the breaker closed.

Second.—The series, or overload coil, which causes breaker to open in case of overload.

Third.—The trip coil T, which releases the lockout and permits the breaker to reclose.

The accompanying cut, Fig. 28, shows the theoretical arrangement of circuits with the breaker in the closed position. The operating coil O is energized as follows: At point A the series coil is electrically attached to the main frame, and a circuit to operating coil is made through cut-out contact C, to pin B, to resistance R − 1, to operating coil O, to fuse L, and to opposite side of line at M.

A high resistance R − 1 limits the current to the operating coil to an amount just sufficient to hold the breaker in the closed position but not enough to start it to close. An arm G is provided for the purpose of shunting R − 1 out of circuit while the breaker is in the act of closing, so that full potential will be applied to close the breaker. At the instant breaker closes, G is opened by the main contact brush and held open by latch H.

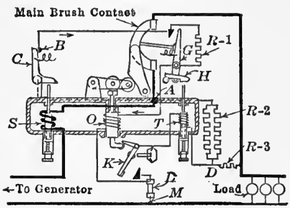


Fig. 28.—Auto-reclosing breaker —closed position—diagram of connections.

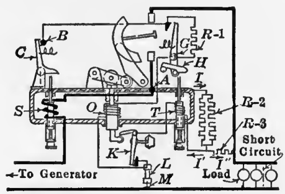


Fig. 29.—Auto-reclosing breaker —open position—diagram of connections.

Opening.—The breaker, being held closed magnetically, will open either in the event of voltage failure or by the momentary opening of the operating coil circuit.

Overload.—When an overload occurs the plunger of overload coils is raised so as to engage cut-out contact arm C and cause it to rotate out of contact with pin B. This results in the de-energization of coil O and the breaker opens.

Voltage Failure.—In case the voltage drops below that necessary to maintain the magnetic seal of the operating plunger, the breaker drops open.

Reclosing.—Fig. 29 shows the theoretical arrangement of circuits with the breaker in the open position. After the breaker has been opened due to any cause, it is necessary for trip coil T to operate, and unlatch H so that arm G will cut out R-l. This allows full potential to be applied to operating coil and closes the breaker.

Before the trip coil can possibly act it is necessary that the dashpot contact arm descend and close the circuit at K. This provides a definite time interval during which the breaker must remain open regardless of the cause of opening. While the main contact brush is open a shunt path is formed from the positive side of the generator around the main contacts through a high resistance R-2 and a low resistance R-3.

Assuming a short circuit remains on the line and the dashpot has settled down so as to complete the circuit for the trip coil, a current I will flow through R-2. The value of the Resistance R-2 is relatively high in comparison with that of the trip coil and the load or short circuit and R-3 which is in parallel with the trip coil. For this reason a practically definite amount of current will flow through R-2 regardless of the load resistance. But the division of this current between the trip coil and load circuit will depend upon the load or short-circuit resistance.

It will be observed that there are two paths whereby current may flow from point D to point M. One of the paths being through a low resistance R-3 to load through short circuit, and back to M. The other path is through the trip coil and dash-pot contact arm to point M. The trip coil is wound with a low resistance so that a slight variation in the short-circuit resistance will also cause a corresponding change of current through the trip coil. So long as a short circuit of low resistance remains on the load circuit the greater part of current I will be shunted around the trip coil through the short circuit, as indicated by I″. However, as soon as the short circuit is removed or the resistance of the short circuit increased to a value which would not permit an excessive current to flow were the breaker to reclose, enough current I will be forced through the trip coil to cause its armature to rise and release latch which results in the closing of breaker, after which the parts assume the position shown in Fig. 28. The breaker does not close or attempt to close while a short circuit or overload of low resistance exists, but does close instantly and automatically upon the removal of short circuit or overload.

Types.—These breakers are made in three different types, depending on the current ratings. The smallest ones made in capacities of 25 to 400 amperes are intended for the protection of branch circuits and have contacts of solid copper with graphalloy arcing tips to take the final break. The medium size for ratings from 300 to 800 amperes have laminated copper brush main contacts, with secondary contacts of copper and graphalloy contacts to take the final break. The largest size, shown in Fig. 30, has contacts similar to the medium sized one. The operating coil and trip coil are completely housed and protected in a cast-iron frame which carries the operating mechanism. These breakers are built in capacities from 1200 to 2000 and modifications of this type are built for 3000 and 4000 amperes.

Fig. 30.—Automatic reclosing circuit breaker. Large size.

These breakers are used for the protection of independent feeder circuits, generator circuits, feeders in a network, or for sectionalizing circuits and can be arranged to take care of the many contingencies in an automatic substation or a plant where the class of attendance is poor.

CONDIT CIRCUIT BREAKERS

Type K-2 breakers illustrated in Fig. 31, are made both front and rear connected in capacities up to 300 amperes at 600 volts D.C. or 750 volts A.C. with underload trip, overload trip, undervoltage trip, shunt trip, reverse power

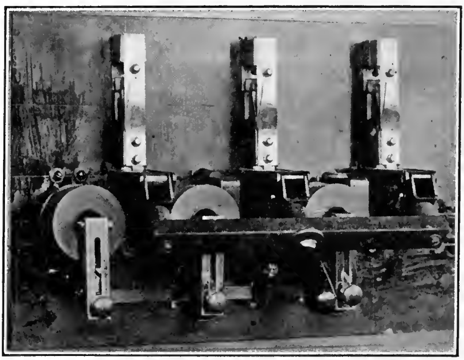


Fig. 31.—Condit Electric Mfg. Co. circuit breaker type K-2.

and time limit. Various combinations of these different methods of tripping may be applied to the same breaker. These breakers are usually made hand operated but can be made electrically operated.

Construction.—While the K-2 air circuit breaker has been primarily designed for industrial application, its finish and general appearance are such that it harmonizes well with instruments and devices usually associated with switchboards.

It consists essentially of three distinct standard units: (1) the upper contact member with its auxiliary metal and carbon contacts, stud and nuts; (2) the movable contact members, comprising the brush with its metal and carbon auxiliary contacts and the operating mechanism, supported by the housing; (3) the tripping coil with its stud, magnetic circuit and calibration plate.

The conducting parts are liberally designed, and the laminated brush is fully protected by relatively massive carbon auxiliaries on which the arc is finally broken. Interposed between the laminated brush and the carbon contacts is a metal auxiliary contact so related to the main brush that proper protection to the current-carrying members is assured. The carbon and metal auxiliary contacts are easily renewable and reversible.

A vibration proof latch holds the breaker normally in the closed position and when released by the tripping coil the moving contact member opens positively and quickly. The magnetic circuit of the trip coils is laminated. This feature is of importance, as it renders overload breakers interchangeable for use on either direct or alternating-current circuits. The breaker is easily closed by a downward movement of the handle, and the mechanism is so arranged that the brush pressure is properly distributed.

Double-pole breakers are arranged for independent closing, but both poles trip simultaneously on overload. Three-pole breakers are arranged with a common handle, causing all poles to be closed and opened simultaneously. Four-pole breakers are not arranged so that all poles are closed simultaneously—two 2-pole breakers are furnished, each having a common handle which causes the two poles to be closed and opened simultaneously.

Barriers are furnished on all multipole breakers above 250 volts D.C. or 440 volts A.C.

Trip Range.—Standard overload breakers, for use on both direct and alternating-current circuits, are calibrated from 80 to 160 per cent. of full-load current.

Air circuit breakers which are seldom opened in the course of regular operation should be periodically opened and thoroughly cleaned.

Type K-1 breakers shown in Fig. 32 are made in capacities from 100 amperes to 5000 D.C., 4400, 25 cycle, 3300, 60 cycle, in 1, 2 or 3 poles and as 6000 and 8000 ampere D.C. single pole for plain overload, plain shunt trip or undervoltage with

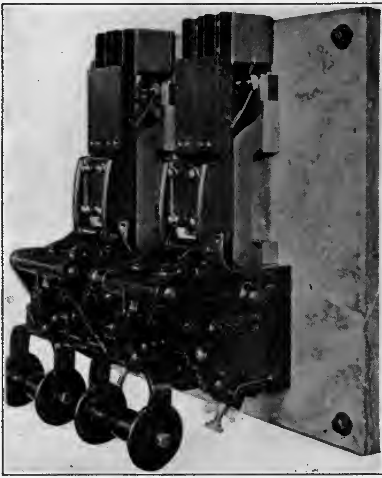


Fig. 32.—Condit type K-1 carbon breaker.

various attachments to secure time limit, reverse power or other features. These breakers are made with round studs up to the 2000-ampere D.C. size and with laminated studs for the larger sizes.

CUTTER—I.T.E. CIRCUIT BREAKERS

The Cutter Company make their "I.T.E." breakers in various forms and capacities for hand operation or electric control depending on the class of service for which they are intended. They adopted the "I.T.E" designation as their earliest breakers were designed to have an "Inverse Time Element" as one of their principal features, the time of tripping being in an inverse ratio to the severity of the short circuit.

Types.—For 250-volt service in capacities from 5 to 300 amperes the E-1 type of breaker is furnished where compactness

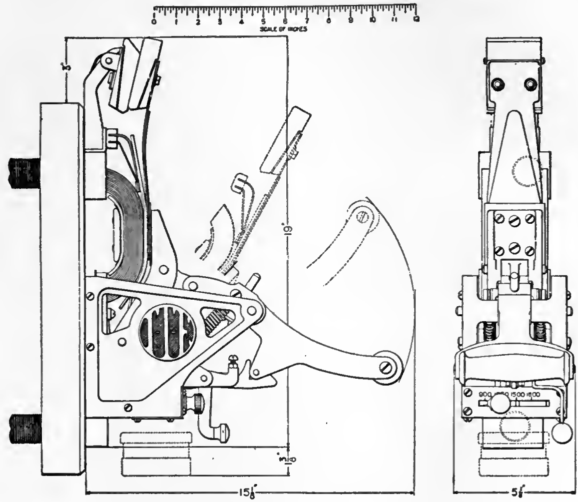


FIG. 33.—Cutter type LL carbon breaker.

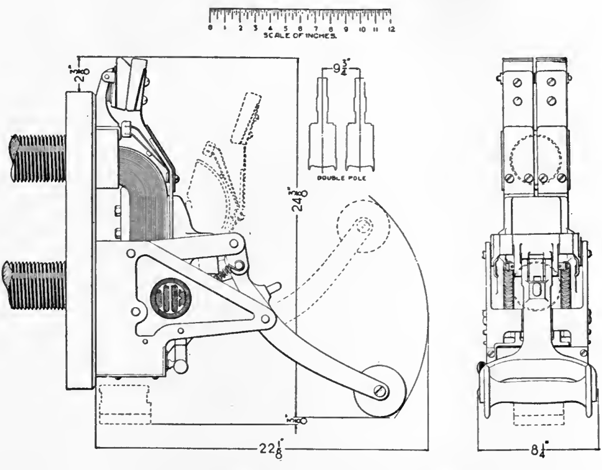


FIG. 34.—Cutter type LG carbon breaker.

is an important feature, this breaker being on a base only $5\frac{1}{2}$ inches wide and 7 inches long.

For capacities from 80 to 1250 amperes at 250 volts or less, the type N-X is used. To secure uniformity of appearance on a switchboard all of the breakers are built on the same frame. If desired these breakers can be provided with no-voltage feature, shunt-trip feature, time limit and bell ringing attachments. The breakers can be made multipole with independent closing arms so that they are adapted for use on distributing circuits without any switches in series with them.

For use on circuits of 750 volts or less the L-L type is built for currents from 200 amperes up to 1600 amperes D.C. or 1250 amperes A.C. As shown in Fig. 33 the brushes of laminated construction rest on the contact blocks at an angle, while for the larger L-G breakers shown in Fig. 34, made in capacities up to 10,000 amperes D.C., the laminated brush is of the end-on butt construction that is found advantageous in large capacity breakers.

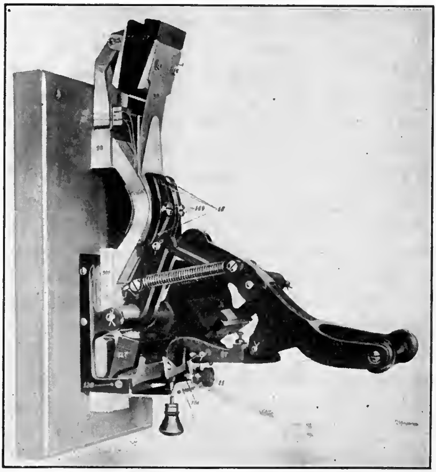


FIG. 35.—Cutter circuit breaker—sectional view.

Operation.—Fig. 35 shows a sectional view of a typical "I.T.E." breaker and the description of the main parts of the breaker and its overload features may be considered as that of a normal high-class American breaker, although those of other makers naturally differ in the details of construction.

The illustration, Fig. 35, shows the details of one form of I.T.E. Circuit Breaker Switch Member. 98 and 50 are fixed terminals mounted upon the front of the base or switchboard. The current entering the instrument at 50 by way of the rear connection stud (not shown), passes through the overload coil 50a into the contact block 50B, thence it passes through the laminated contact member or bridge 16, into the upper terminal and out at the rear by way of a threaded stud (not shown). A by-pass of somewhat higher electrical resistance than that of the main contact member is offered by the flexible copper strip 3, through which the current from the lower contact block passes to the spring plate 30, thence to secondary metallic contacts 69 and 81 and the final or breaking contacts 27 and 75, which consist of carbon blocks.

The action in opening the circuit is as follows: The laminated member first moves out of contact with the terminal 98, co-incident with which the current is shunted through the secondary path which, though of higher resistance than the main contact member, has sufficient conductivity to prevent the formation of any arc at the main contacts. The circuit between the secondary metallic contacts 69 and 81 is next interrupted, throughout which action the carbons are maintained in full contact. The circuit is finally broken by the separation of the carbons which are highly refractory, and upon which the action of the current is not such as to impair their usefulness.

The most widely used circuit breakers are those which open in the event of overload or excessive current. The operation of the overload feature depends upon the volume of current only, regardless of its direction and is independent of the voltage of the circuit.

Overload Feature.—One form of I.T.E. overload feature is shown. The principal parts are an armature 127 and magnet 59 energized by a winding 50a, carrying the main current of the circuit in which the circuit breaker is connected. The armature is pivoted on pins 128, and is normally held by gravity out of engagement with the magnet against an adjustable stop 136, and is adapted, when the current exceeds a predetermined value, to be drawn forcibly against the magnet, toward the completion of which movement it impinges upon the latch 87, which normally holds the switch member of the circuit breaker closed against the action of the opening springs. The normal or "at rest" position of the armature is subject to convenient adjustment by movement of the stop 136, by means of knob 11, so that the distance between magnet and armature may readily be varied, the volume of current required to move the armature into engagement with the latch being correspondingly varied; the closer the armature is to the magnet the less the current required to actuate it to trip the circuit breaker. The volume of current which will cause operation of the overload feature at various positions of the armature is suitably indicated along the calibration scale 13.

Reversite.—Where D.C. generators operate in parallel or are used with a storage battery a reverse-current feature is usually found advisable to cut off a generator if the other generators or the battery tend to force current into the unit. The term "Reversite" is applied to these Cutter breakers that have this reverse-current feature.

Remote-control circuit breakers and switches have the advantage that they do not require to be massed together upon a single switchboard, but may be located in such a manner as will afford the most convenient and economical cable installation; for while remote-control apparatus may be scattered around in various parts of the plant as conditions dictate, the control may readily be brought to any point determined upon as the most convenient for this purpose. The switches and indicating devices for controlling a large number of circuit breakers may be placed upon a bench board of insignificant dimensions, so that a large installation may be placed, by this means, virtually under the eye and within easy reach of a single operator.

Motor Operated.—The reliability of motor operated circuit breakers depends in no small degree upon the perfection of apparently minor details, and every such feature is given most careful attention.

The motor operated device for closing a circuit breaker must fulfill two conditions: it must, regardless of voltage variations in the control circuit, communicate to the circuit breaker the exact movement required to latch it, and it must instantly disengage from the circuit breaker when the act of closing is completed. As the result of failure to fulfill either of these conditions the circuit breaker would remain under the restraint of the closing mechanism and would fail to respond properly to overload or other abnormal condition which should cause its opening.

The means employed to meet these very exacting requirements are indicated on Fig. 36, where the essential working parts of the I.T.E. Motor Operated Circuit Breaker are diagrammatically shown. The movement of the motor in closing the circuit breaker is communicated to a gear sector A by means of a worm B, ball and socket jointed to an extension of the arma-

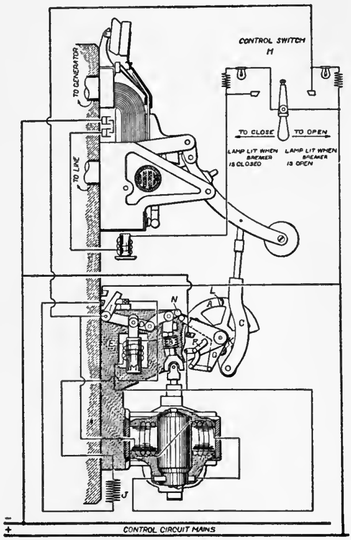


FIG. 36.—Cutter circuit breaker—motor operated.

ture shaft. The gear sector is in turn connected by means of a link C to the circuit-breaker operating arm. Except during the act of closing the circuit breaker electrically, the worm is held out of mesh with the gear sector by the toggle D, which is acted on by the weight of the magnetic core M. This core is adapted to be lifted by the engaging coil E when same is duly energized. The circuits of both motor and engaging coil, which is connected in parallel with it, are under control of the timing switch F. The relations between this switch and the circuit breaker are such that when the circuit breaker is open, the switch is closed, and vice versa.

With the circuit breaker open, and the timing switch in its corresponding closed position, the motor may be brought into operation from the control station by means of an appropriate switch indicated at H. This starts the motor through the resistance J, and also energizes the engaging coil, which, through the plunger acting on the toggle D, forces the worm B into engagement with the gear sector A, which in turn communicates the movement of the motor to the circuit breaker through the link C. The movement of the toggle D is also communicated to the localizing switch I which connects the motor directly with the control circuit and renders its further movement independent of the control switch. At the completion of the closing movement, the stop K on the gear sector comes into engagement with the bell-crank lever G, causing it to open the timing switch, thus disconnecting the motor and engaging coil; the heavy core M associated with the latter is then directed upon the toggle D, disengaging the gears so that further movement of the motor armature will not be communicated to the circuit breaker. The disengagement of the gears is further insured irrespective of the action of the timing switch by the upper arm of the bell-crank lever being directed, in its final movement, against an extension N of the toggle, forcing it into the open position. Should the motor overtravel from any cause whatever, its own excess movement thus serves to disengage it from operative connection with the circuit breaker.

Should abnormal current condition exist upon closing, the circuit breaker is ready to respond instantly and opens immediately without restraint or drag from the operating mechanism. The final movement of the circuit breaker in opening is communicated through the stop L to the bell-crank lever, thus closing the timing switch and again placing the motor circuit in condition to be closed from the control station. The position of the circuit breaker, whether open or closed, is indicated by the lamps associated with the control switch.

Solenoid Operated.—The magnetically operated circuit breaker of the overload type shown in Fig. 37 may be closed on normal load, but immediately releases if closed electrically on overload; hence, the usual switch in series may be omitted, a provision allowing the utmost simplification of switchboard construction. The cable installation in conjunction with direct-current generators operating in parallel may often be greatly simplified by using these breakers (made without overload feature) as equalizer switches. By mounting them on pedestals alongside of the respective generators they materially shorten

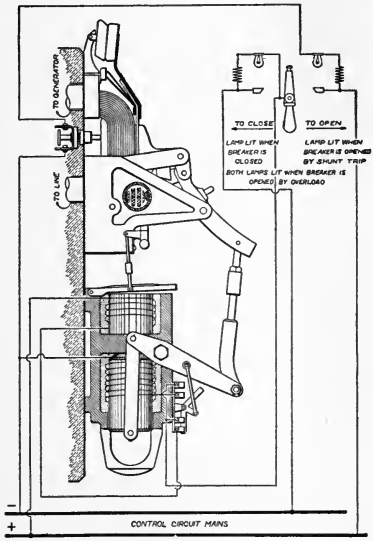


Fig. 37.—Cutter circuit breaker—solenoid operated.

the equalizer leads, rendering it unnecessary to run these cables to the switchboard. This is of especial advantage where the switchboard is located at a considerable distance from the generators.

Among the various mediums employed for the actuation of mechanical devices, none has proved more reliable under a wide variety of most exacting conditions than compressed air. The air brake, the electro-pneumatic signal and the pneumatic drill offer convincing illustrations of this fact. Exposed to changing atmospheric conditions and sometimes handled by the roughest class of labor, they do their work with unvarying reliability and effectiveness.

Pneumatically Operated.—The I.T.E. pneumatically operated remote-control circuit breaker, Fig. 38, embodies the simplest possible method of controlling the circuit breaker from a distance. The operating feature consists primarily of a double-acting piston moving within a cylinder, each end of the latter having a valve-controlled connection with the compressed air supply. The circuit breaker is opened by a movement of the control valve in one direction admitting air to the upper end of the cylinder; the closing of the circuit breaker is caused by an opposite movement of the control valve admitting air to the lower end of the cylinder.

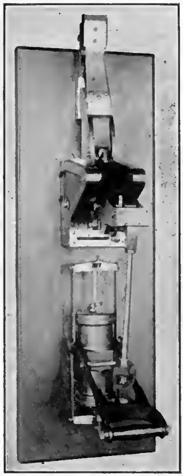


Fig. 38.—Cutter circuit breaker—pneumatic operated.

The circuit breaker furnished in connection with the class of control has the "Autoite" feature, allowing the switch member to open independent of the movement of the closing arm. Should the attempt be made to close the circuit breaker upon overload, it is free to respond instantly and without restraint from the closing mechanism. After it has been so opened, two movements of the control valve are necessary to close it; one movement admitting air to the upper end of the cylinder, forcing the handle lever into engagement with the switch arm; a second movement admitting air to the lower end of the cylinder, finally closing the circuit breaker. Where the operator is sufficiently near the circuit breaker to have it in view, the control valve may be operated by hand. Where the instrument is located at a considerable distance from the point of operation, the valve may be operated electrically, suitable signals at the point of control indicating the open and closed positions of the circuit breaker.

The simplicity and ruggedness of this type of apparatus especially adapts it for use in mills and foundries; also to installations in which the apparatus is exposed to atmospheric changes.

Electro-pneumatic.—Fig. 39 shows a remote-control I.T.E. circuit breaker with electro-pneumatic control. It is of 6000-amperes capacity for 600-volt service, and illustrates one of a considerable number made for a large metropolitan railway system. These circuit breakers are mounted in stations along a portion of the road and form the connections between successive sections of the third rail. They are used to automatically disconnect such sections of the rail as may be grounded and to reconnect them when normal conditions have been re-established.

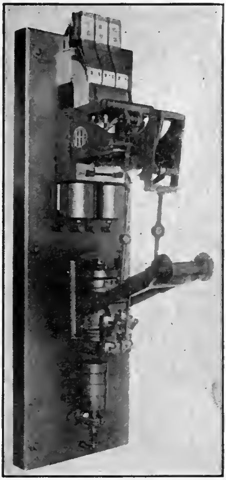


Fig. 39.—Cutter circuit breaker—electro-pneumatic.

The system in which these circuit breakers are installed was already supplied with compressed air equipment used for operating signals and there were also a number of telephone cables available for use as control circuit wires. These conditions made the installation of compressed air operated apparatus especially economical and had considerable weight in determining the selection of this type.

GENERAL ELECTRIC CIRCUIT BREAKERS

The General Electric Company have a very complete series of carbon circuit breakers for various kinds of service. For light duty in isolated plants, the type CG is furnished for A.C. or D.C. service in capacities from 3–300 amperes for voltages below 550 D.C. or 600 A.C. and these can be furnished for overload, underload, shunt trip, reverse current, undervoltage and combination of these.

Type CP.—The CP breaker shown in Fig. 40 is a high-grade switchboard breaker, made in capacities from 15–1200 amperes for A.C. or D.C service in voltages up to 650, with the various methods of tripping and the usual attachments.

The force applied to the handle closes the breaker through a simple strong toggle mechanism which acts directly on the brush. The toggle joint gives a very heavy pressure at the brush with minimum pressure on the handle, making the breaker very easy to close. The heavy brush pressure insures good contact and also assists in rapid opening when the breaker is tripped.

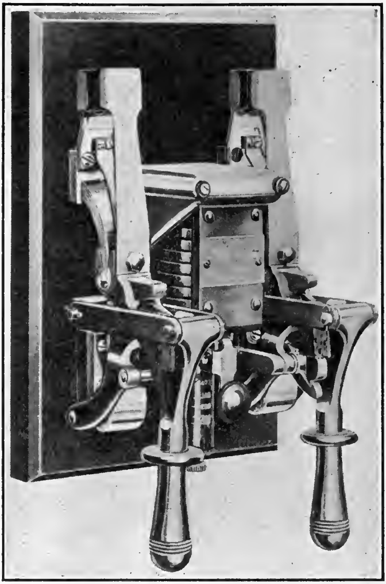


FIG. 40.—General Electric Co. circuit breaker type "CP."

Contacts.—The main brush is of special form. Laminations make "end-on" contact with heavy and uniform pressure over entire contact surface without tendency to force any part of brush out of contact. The cross-sectional area of the brush is ample for the amount of current it is designed to carry, and the form of the brush permits the maximum pressure between the laminations and the contact block.

A burning tip is provided for each pole so that burning of the main brush is prevented. Burning tips close with wiping action. They are easily replaced at small expense.

Secondary contacts are solid blocks of selected carbon, shaped to fit accurately in the holders to which, after being copper plated

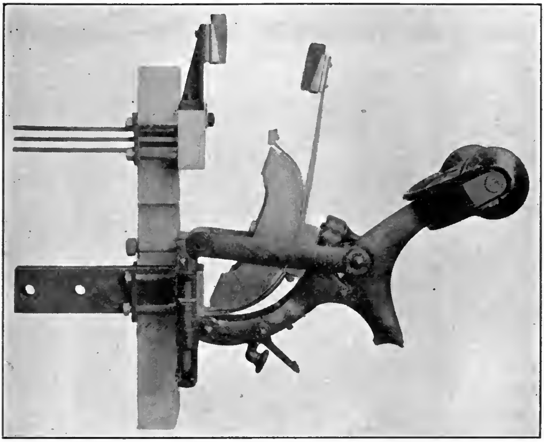


FIG. 41.—General Electric Co. circuit breaker type CK.

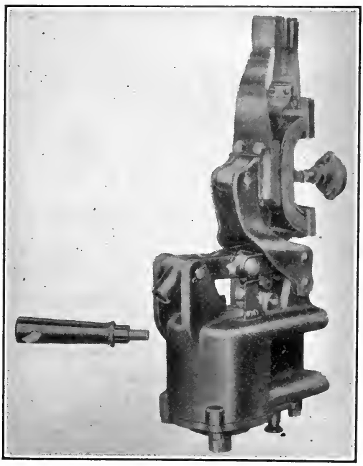


FIG. 42.—General Electric Co. circuit breaker type "CP3."

and tinned, the carbon contacts are securely sweated. No screw holes or grooves are used in the carbons. The carbon contacts are closed under pressure with a wiping motion which insures good contact.

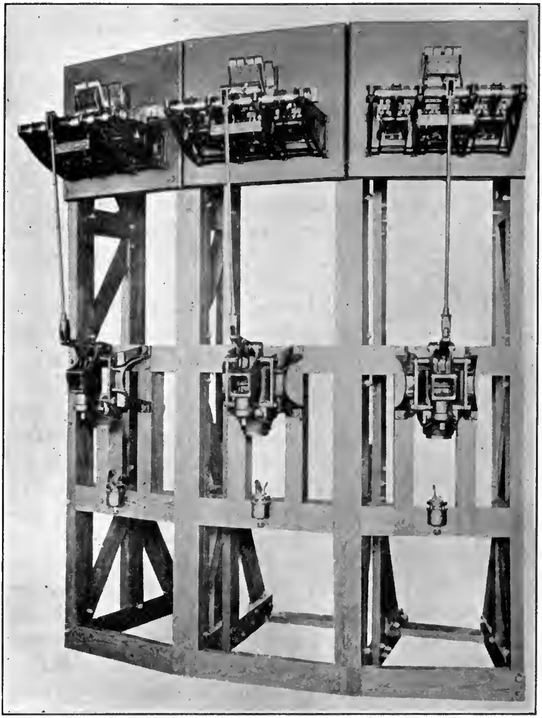


Fig. 43.—12,000-amp. G. E. carbon-break circuit breaker.

When the breaker opens, the brush first breaks contact; next the burning tip and finally the secondary carbon contact. This sequence of operation prevents all burning of main brush contacts.

Type CK.—The type CK is a high-grade switchboard breaker for 250 volts D.C., 1500–6000 amperes and for A.C. 480 volts, 1500–3500 amperes. The CK-2 is intended for 650-volt service and is built in sizes 1500–10,000 amperes D.C. and 1500–3500

A.C. These breakers are shown in Fig. 41, the main difference in the two types being in the length of the carbon arms. Their general features are like the C.P.

On the CK-2 breaker, the arm carrying the carbon secondary is locked in position under full pressure until the main brush has opened a certain distance, after which the secondary contact arm rapidly swings forward and widely separates the secondary contacts. Current passing through the breaker energizes the magnetic circuit around the lower stud and attracts the armature, which strikes the latch a hammer blow and trips the breaker.

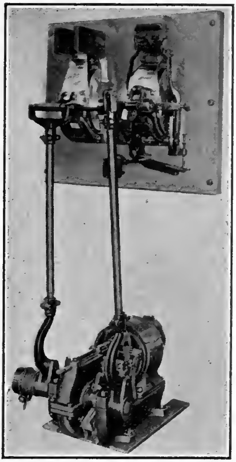


Fig. 44.—General Electric Co. circuit breaker motor operated with switch.

A positive locking latch holds the breaker closed. Latch is so constructed that breaker will not jar open, but will trip easily without aid of accelerating devices.

Solenoid Operated.—For solenoid operation the breakers are designated as CP-2 and CP-3 and these contain the same features as the corresponding hand operated types. The arrangement of the solenoid mechanism is shown in Fig. 42. The plunger of the closing coil acts directly on a simple toggle to close the breaker and the construction is such as to give a very heavy pressure on the brush contacts. A removable handle is conveniently located and insulated from the live parts of the breaker. A removable handle is provided for inserting in a socket of the mechanism for hand closing.

Heavy Breakers.—Special breakers for very heavy A.C. currents are usually made with the solenoids mounted separately from the breaker, as shown in Fig. 43, this being a breaker furnished to the American Woolen Company, at Lawrence, Mass., to carry 12,000 amperes continuously at 40 cycles, 600 volts.

Motor Operated.—An interesting combination of motor operated carbon breakers and brush type of switch is shown in Fig. 44, of which there were 190 switches furnished on the original contract for the substations of the New York Central Railway.

When the control switch is manipulated on the switchboard the motor is started and the carbon break circuit breaker is closed. Further rotation of the motor disconnects it from the breaker mechanism and connects it to the switch mechanism which it closes in turn. If there is a short on the circuit the breaker is free to trip out and open the circuit.

ROLLER-SMITH CIRCUIT BREAKER

The Roller-Smith breaker is made in capacities of 5 amperes to 6000 amperes for 250 volts and 600 volts, multipole breakers being built up to 1000 amperes and the large ones being made single pole only. The breakers can be supplied for overload or underload or both and reverse current and other features can be secured through relays.

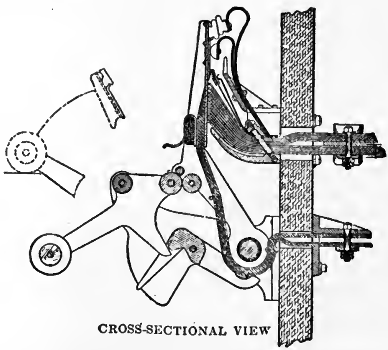


Fig. 45.—Roller-Smith carbon-break circuit breaker.

The R–S breaker shown in Fig. 45 is closed by pulling down the handle to the position shown in cut. The arm is under compression against the brush and tends to open on account of the spring of its coil, but it is held closed by the roller on the handle (which is slightly over the center line between handle bearing and roller on arm). A slight kick from the armature knocks it back across the center line and the breaker flies open. There are no latches or triggers to hold arm closed, merely the rollers which are non-rustable and practically without any wear.

There is an eccentric pin stop for the roller which limits the distance it passes over center. The breaker may thus be made more or less sensitive as desired. This cut shows the construction in sizes over 1200 amperes, in which the laminations are continuous from brush to bus bar. In other respects the construction of smaller sizes is similar.

The industrial type of circuit breaker is built in capacities up to 100 amperes for voltages up to 250 D.C. and 440 A.C. They are made either front or rear connection and are of simple and rugged design.

WESTINGHOUSE CIRCUIT BREAKERS

The Westinghouse Electric & Manufacturing Company, who were one of the first to develop the Carbon Circuit Breaker, have complete lines of breakers from the type F that is built in capacities up to 75 amperes, 250 volts, up to the largest capacity for which there is any demand.

Type F.—The type F are small and compact single-pole carbon breakers. They readily take the place of switches and fuses and occupy about the same space as a fuse block and fuse. They are designed to fulfill a demand for a protective device to be used with small motor and lighting installations, and have a cost commensurate with those of such systems.

The overload-operating solenoid is inside a fibre tube forming the lever arm. The tripping point may be set for any current within the tripping range by a little knurled thumb screw located below the pivot. A small insulating knob at the right controls the tripping device and offers a means of opening the breaker by hand.

The current-carrying contacts are copper, the arcing contacts are carbon and are readily renewable. The lower arm is operated by a spring and the copper contacts are of a shape to assist in opening the breaker.

Type CD.—Type CD carbon circuit breakers shown in Fig. 46 are supplied for separate or panel mounting. These breakers are supplied for voltages up to 750 and for capacities up to 300 amperes. They may be used for motor starting-control of industrial circuits and as feeder circuit breakers in moderate size. The main or brush contact is made of laminated copper having high-pressure contact with an excellent wiping or self-cleaning action. When the breaker is opened, the main contact is opened first and the current is shunted upward through auxiliary contacts where the circuit is broken. The secondary contacts

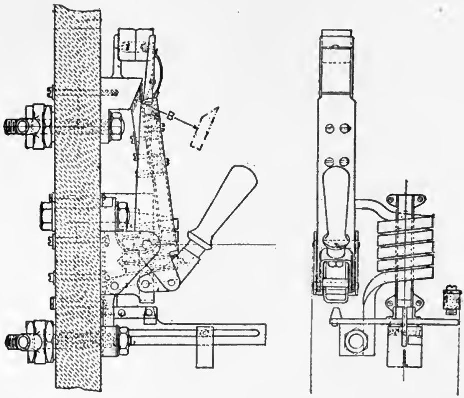


Fig. 46.—Westinghouse carbon circuit breaker, type CD.

Fig. 47.—Westinghouse circuit breaker type "CC."

are of flat phosphor bronze. The arcing contacts are of carbon and have a wiping action, making them self-aligning and self-cleaning.

Type CC.—The type CC carbon circuit breaker shown in Fig. 47 for protection of alternating-current and direct-current circuits of moderate capacities are supplied for voltages of 750 or less and for capacities up to 800 amperes. These breakers are manually operated and are closed by pulling down on the operating handle, and may be tripped manually by pushing upwards on the handle or back on the calibrating thumb knob. In closing a breaker, the brush is forced against the contact plates by means of a toggle-joint lever. A small steel roller engages a locking catch, places the two releasing springs under tension, and holds the breaker in the closed position. Friction clips, which engage a projection on the handle eliminate any destructive effects of jarring due to the opening of the breaker.

Fig. 48.—Westinghouse carbon circuit breaker, type CA.

Contacts.—The main contacts are made of laminated copper brushes and attached to the upper end of each movable contact is a phosphor-bronze secondary contact that bears on the main stationary contact when the breaker is closed, and opens after the main brush has entirely left the contact plate. By this means, the opening of the circuit is transferred from the main contacts and, in case of any possible failure of the carbon arcing contacts, the main contacts are protected from the arc.

Each breaker is also provided with auxiliary carbon arcing contacts which finally interrupt the circuit, thereby preventing any burning of the main contacts when the breaker opens. The stationary carbon contact is securely fastened to the stud immediately above the upper stationary main contact. The movable carbon contact is mounted immediately above the movable main contact to which it is connected by a shunt composed of braided flexible copper. This contact is so mounted that the main and secondary contacts are open about one-quarter inch before the carbons separate, thus eliminating any possibility of the metallic contacts being blistered by the arc. The movable carbon contact is pivoted on the supporting frame in such a manner that it is in perfect alignment with the stationary contact whenever the breaker is closed. These carbon contacts are inexpensive and readily renewable.

Type CA.—Type CA carbon circuit breakers, Fig. 48, are designed particularly for the severe current-carrying and interrupting conditions found in operating low voltage direct and alternating-current systems. They are made in the following capacities, based on 30-degree Centigrade rise:

Maximum Amperes

For circuit		Max. volts	Manually operated direct control	Manually operated remote control	Electrically operated
Current	Frequency cycles				
Direct	..	750	24,000	.....	24,000
		1,500	......	2,500	8,000
Alternating	25	750	10,000	.....	10,000
	60	750	7,000	.....	7,000

Distant Control.—When conditions make it desirable to operate carbon circuit breakers from a distance, the electrically operated form or the manually operated remote control, within its limited application, is furnished. This makes it possible to install the circuit breaker near the apparatus to be connected, like the equalizer connection of a direct-current generator, and to retain the control at the switchboard. Another common application of the electrically operated form is for remote-control feeder tie switches on distributing systems. Such arrangements effect a saving in wiring, as a light control cable takes the place of the heavy power cable otherwise required.

The simple form of toggle mechanism used throughout is especially worthy of note. This toggle on all sizes, from 3000 to 24,000 amperes, consists of but a single link member connecting the handle lever and main contact arm, but is so shaped and related to the lever members as to form an eccentric toggle of exceptional power. In the sizes below 3000 amperes the toggle is of the roller type, formed by means of a roller on the inner end of the handle lever acting directly on a plane surface on the brush-arm or main contact lever. Both forms are best adapted to the particular sizes of breaker and form the simplest mechanism known to be used for the purpose. The automatic overload tripping attachment is contained in the circuit breaker and forms an integral part of it.

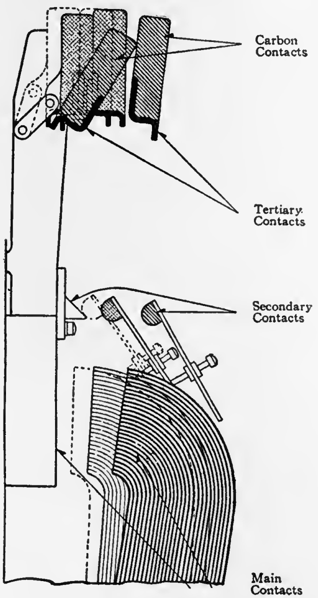


Fig. 49.—Westinghouse Type CA breaker—contact arrangement.

Contacts.—In larger capacities, where the moving contact is subdivided in order to obtain a better average distribution of contact pressure, large ventilating spaces are allowed between the individual laminated main contact members. This reduces the temperature rise very materially under any given conditions of load and increases the capacity on alternating-current service by reducing the "skin effect." When the breaker is tripped, the main contacts are opened first and the current is shunted upward through copper secondary and tertiary contacts to the carbon arcing contacts where the final break takes place. See Fig. 49.

This shows the shape and relative position of each of the contacts in the three important stages of breaking the circuit, as follows:

1. Contacts outlined by dotted lines show main brush opened, secondary contact on point of opening and tertiary and carbon contacts not changed from closed position.

2. Contacts shown by light shading show main and secondary contacts open, tertiary and carbon contacts still closed, but one set of contacts has slid down on the other set.

3. Contacts shown by heavy shading show the tertiary contact open and carbon tips about to finally break the circuit.

Directly over the brush contacts the secondary contacts are located. The secondary stationary contact has a surface inclined to the vertical and practically parallel to the plane of support of the moving contact spring, thus preventing buckling of the spring in case the contact is roughened by repeated opening under short-circuit conditions. The moving contact spring is held under initial pressure until just before the contacts separate. The secondary contacts open next after the main or brush contacts open, protecting the latter from arcing under severe short-circuit conditions.

An adjusting screw on the moving contact allows an adjustment of the relation of the opening of the main and secondary contacts.

The tertiary contacts are attached to the lower end of the carbon contacts of which they appear to be a part. They are made of copper and are connected to the main or brush contacts by heavy copper shunts. They open immediately before the carbon contacts open and fully protect the secondary contacts except under extreme conditions of repeated short circuit without proper maintenance.

The carbon or final contacts, except where exposed to the arc, are heavily copper coated or filled, thus insuring lowest-resistance contact with the tertiary-contact copper plates and the shunts to the main contacts. They are self-aligning and have a self-wiping action, thus making them self-cleaning.

The carbon arms are of ample length and open far enough to insure breaking the heaviest arc incident to short circuit, as in heavy railway service.

Contactor Type.—A line of breakers known as the type CA contactor-type circuit breaker (see Fig. 50) is available in capacities from 1000 amperes to 8000 amperes direct-current, inclusive, and in intermediate capacities corresponding to the regular type CA single-pole line. The term "contactor type" means a breaker that is electrically operated, but held in the closed position by the presence of a small amount of closing current on the operating magnet and not by a mechanical latch, as is usual with the standard manually or electrically operated type CA breakers. The breaker drops to the open position on the absence of voltage in the control circuit. The contactor type of electrically operated breaker is much more simple than the standard electrically operated form, which has all of the parts of the regular manually operated breaker and the electric operating mechanism in addition. However, they are made only in the single-pole non-automatic form, which accounts for part of the simplicity.

FIG. 50.—Westinghouse contactor type breaker.

The contactor breaker is made automatic by the addition of overload or reverse power relays arranged to open the closing coil circuit or to short-circuit the closing coil with resistance in series. The latter relay scheme permits the use of standard contact-closing relays.

The contactor breaker is adapted for use as an automatic feeder tie switch in conjunction with appropriate relays and connections. In this service it is adjusted to open when the voltage drops below a certain predetermined limit, as would be caused by an excessive overload or short circuit in the vicinity. The breaker will then remain open until some predetermined voltage exists on both feeders that it is arranged to tie, and then automatically closes.

Multipole contactor breakers are made by using several single-pole units controlled by a single control switch or relay or both.

Manually Operated Remote-control Breakers.—For service up to 1500 volts direct current and capacities up to 2500 amperes, single-pole type CA manually operated breakers are supplied for mounting above or away from the switchboard panels, but operated from a handle mounted on the panel in the usual location for the knife switch. See Fig. 51.

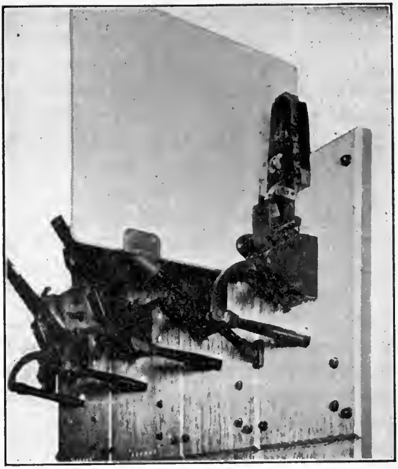


FIG. 51.—Westinghouse remote-control 1500-volt breaker.

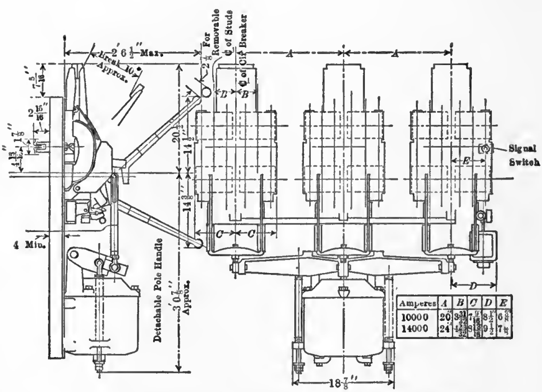


FIG. 52.—Westinghouse electrically operated breaker.

Multipole Circuit Breakers.—Each multipole breaker is provided with a common trip; that is, an overload on any one pole trips all poles. The manually operated breakers (two, three or four-pole), up to and including 2500-amperes capacity can be provided with a single closing handle and crossbar for closing all poles together (all poles tripped together). This form of handle is arranged, by springs, to retrieve independently of the breaker pole units so as not to retard the operation of the breaker on opening.

Solenoid Operated.—The electrically operated multipole breakers, Fig. 52, are supplied in any standard number of poles and in any standard ampere capacity in which the type CA line is listed. They have a common electromagnet for closing all poles and a single shunt-trip magnet acting through a common trip mechanism for tripping all poles of the breaker together.

Direct-current shunt-trip attachments arranged for mounting on the front of the panel are made for all capacities of manually operated type CA breakers.

A direct-current automatic undervoltage-trip attachment is made for the several capacities of type CA breaker. This attachment is reset automatically by the opening of the circuit breaker.

An inverse time limit dashpot with an adjustable time feature is made for all sizes of CA breakers up to and including 2500 amperes direct current and 1600 amperes alternating current, in any number of poles up to four poles, and for both manually and electrically operated breakers. A similar attachment for the larger capacity breakers can be supplied.

An attachment for tripping the type CA carbon circuit breaker on reversal of current in direct-current service is made to be applied to any regular type CA carbon circuit breakers of capacities up to 20,000 amperes.

CHAPTER IV

OIL CIRCUIT BREAKERS

Application.—It is generally conceded that for opening large amounts of alternating-current power and for controlling all alternating-current high völtage circuits nothing at the present time is superior to oil circuit breakers. There are three fundamental reasons for this: First, the fact that this type of breaker terminates the alternating-current wave at its normal zero value, eliminating excessive surges in the connected circuits; second, the compactness of form of the apparatus; and third, the fact that this type of apparatus properly designed reduces the fire and life hazards to a minimum.

When an oil circuit breaker is opened under load, an arc is formed between the stationary and the moving contacts, the size of the arc depending upon the voltage, the amount of current, and rate of contact separation. The heat of the arc disintegrates some portion of the arcing contacts and some of the oil surrounding the contacts, forming a gas bubble of a size that depends on the amount of current flowing and on the duration of the arc. If this gas bubble is immediately carried away from the contacts and the contacts have been sufficiently separated, the arc will persist only until the next zero of the current wave. The ability of the bubble to rise away from the contacts depends upon the relative specific gravity of the gas and oil, and the head, volume, and viscosity of the oil. Oil having high specific gravity and sufficient head will exert pressure enough to force the bubble up and away from the contacts, irrespective of their position.

Features.—The following features apply to practically all high-grade American oil-circuit breakers of any make, and are generally recognized as embodying the best practice.

These are: open position maintained by gravity, so that the contacts fall to open position in case of injury to the moving contacts or the lifting rods; the rapid acceleration of the moving parts on opening to minimize the duration of arcing, the tank pressure, and the deterioration of the arcing contacts; all live parts immersed under a deep head of oil to absorb the shock of short circuits and to prevent the excessive development of gases when rupturing large amounts of power; proper venting and baffling arrangements for oil tanks to provide regulated escape for the gases formed by rupturing heavy overloads and short circuits; sturdy mechanical construction throughout; isolation of individual poles in insulated cells on moderate voltage service, and in separate tanks on high voltage; use of generously proportioned high-pressure wiping and self-cleaning contacts; protection of the main contacts by arcing contacts so located that the main current exerts a blowout effect on the arcs; use of electric solenoid for electric operation and the use of full-automatic design of latching devices, preventing the possibility of holding the contacts in the closed position when heavy overloads and short circuits exist on the line.

The type H-3, H-6, and H-9 breakers of the General Electric Company form a notable exception to some of the features described above as their moving contacts are downward closing, motor operated, but they embody many of the other features and have been remarkably successful in their actual performance.

Rating.—The selection of an oil circuit breaker for application to an electrical system or circuit requires a knowledge of the characteristics of the breaker and the characteristics of the system or circuit. Breakers are usually classified according to their rated voltage, rated current, rated frequency, interrupting capacity and instantaneous current capacity. Systems may be classified according to their normal operating voltage, normal current, normal frequency, and current transients.

The rated voltage of a breaker is the greatest normal voltage as read by voltmeter in volts between any two wires of any circuit to which the breaker should be connected. When referred to the breaker, it is a function of its insulation strength and of the safety factor desired. The American Institute of Electrical Engineers has established standards for the insulation strength of oil circuit breakers. All high-grade indoor oil breakers are tested at $2\frac{1}{4}$ times rated voltage plus 2000 volts, and all outdoor oil breakers will stand the wet test of twice rated voltage plus 1000 volts as specified in these rules.

Altitude.—Standard ratings of oil breakers are good for altitudes of 3300 feet above sea level and less. For higher altitudes, standard breakers must be used on voltages less than rated voltage, the amount of derating depending on the altitude. For operation above 3300 feet the voltage ratings given must be multiplied by the following factors:

Distance above sea level, feet	Voltage rating factor (G.E. Co.)
4,000	.874
6,000	.825
8,000	.775
10,000	.728
12,000	.684
14,000	.64

For applications at high altitudes, circuit breakers equipped with special terminals can be supplied as special and should be taken up with the manufacturing company.

The normal operating pressure of a system is the greatest pressure in volts ordinarily maintained between any two conductors.

Rated Current.—The rated current of a breaker is the greatest current in amperes which it will carry continuously at a specified frequency without any essential part having its temperature raised more than a specified number of degrees above an ambient temperature, or above a fixed temperature. The American Institute of Electrical Engineers has established heating standards for oil circuit breakers. They limit the maximum permissible temperature rise of coils and insulating materials of oil circuit breakers 65 degrees Centigrade based on an ambient temperature of 40 degrees Centigrade, and the rise of other parts whose temperature does not affect the temperature of the insulating material to be such as not to be injurious in other respects. They also limit the maximum temperature of oil and contacts in oil to 70 degrees Centigrade. For an ambient temperature of 40 degrees Centigrade, this permits a temperature rise of 30 degrees Centigrade for oil and contacts in oil. Where, however, the ambient temperature is less than 40 degrees Centigrade, advantage may be taken of the condition to operate the parts at a higher temperature rise if the maximum temperatures specified are not exceeded.

Inasmuch as a circuit breaker reaches its final temperature quickly with steady current load, it is necessarily a maximum rated device. On 25-cycle service a circuit breaker above 300 amperes rating will carry, continuously, considerably more than its 60-cycle rating, and 25-cycle current ratings are therefore given on 600 ampere breakers and above.

Interrupting Capacity.—The interrupting capacity of an oil circuit breaker is the highest current in amperes which it will interrupt at any specified normal pressure, frequency and duty. This conforms with the standards adopted by the American Institute of Electrical Engineers.

The duty on which the ampere tables have been based assumes that the breaker will interrupt a circuit two times at a 2-minute interval and then be in condition to be closed and carry its rated current until it is practicable to inspect it and make any necessary readjustments. This definition of interrupting capacity selects the most common condition of oil circuit-breaker operation.

The duty performed by a circuit breaker in interrupting the current at a given voltage is dependent upon the current volume and is a maximum for the largest current. Similarly, the duty at varying voltages for a given current is increasingly more difficult at higher voltages. A given breaker equipment for any voltage—within its rating and under proper normal adjustment—has a certain maximum current interrupting ability. It should not be applied to a service demanding interrupting capacity beyond this ability.

Rating.—The proper method of rating breakers was long a debatable question and caused a considerable amount of misunderstanding when comparing various breakers.

A. I. E. E., 1916.—In the September, 1916, *Proceedings* of the A. I. E. E. there were two papers presented, one by Mr. E. M. Hewlett, of the General Electric Company, and the other by Mr. S. Q. Hayes of the Westinghouse Electric & Manufacturing Company, on this subject of circuit-breaker ratings, and these papers with the resulting discussions did a good deal to pave the way for a more definite method of rating circuit-breaker rupturing capacities.

A. I. E. E., 1918.—A later meeting of the A. I. E. E. in February, 1918, was devoted to the consideration of a paper prepared jointly by Mr. G. A. Burnham, of the Condit Electrical Manufacturing Company, Mr. E. M. Hewlett, of the General Electric Company, and Mr. J. N. Mahoney, of the Westinghouse Electric & Manufacturing Company. This paper contained a great deal of

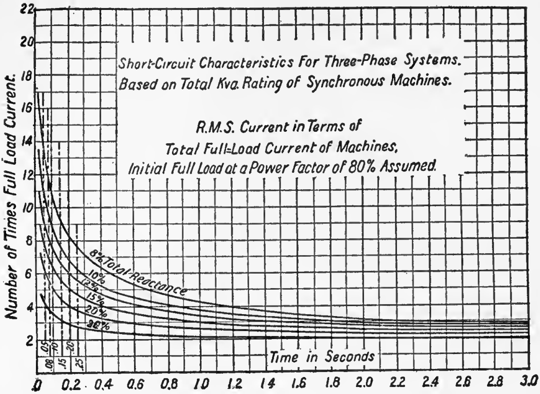


Fig. 53.—Short circuit characteristics—30 per cent. reactance or less.

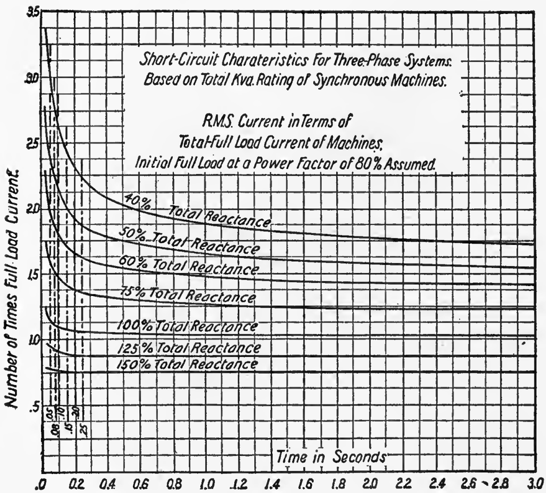


Fig. 54.—Short circuit characteristics—40 per cent. reactance or more.

valuable data in the form of curves of the short-circuit conditions to be met with in the average plants of different reactances at the expiration of different lengths of time. These curves were based on an average of a large number of curves of actual modern generators built by the General Electric Company and the Westinghouse Electric & Manufacturing Company, and can be taken as representative of present American Generator Design.

Short-circuit Curves.—These curves slightly modified for convenience are reproduced in Figs. 53 and 54 and they show very clearly how the short-circuit values die down very rapidly after a small fraction of a second, and how the reactance of the system has a great deal to do with these values.

The characteristic shapes of the time current decrement curves have been arrived at by analysis of alternator tests including oscillograph studies of short circuits occurring when the alternators were excited to full voltage and were carrying various loads at various power factors.

In the curves for total reactances up to and including 20 per cent., the reactance is assumed to be wholly within the alternator and for higher values of reactance the alternators were taken at 20 per cent. and due allowance made by calculation for the effect of the external reactances.

The final values of the current, *i.e.*, the sustained short-circuit current, have been assumed in accordance with experience and tests and are based on the behavior of machines of normal design.

The percentage reactance in any leg of a circuit is the reactance drop in that leg of the circuit at normal current expressed as a percentage of the voltage to the neutral of that circuit. The percentage values are initial values based on a symmetrical sine wave and on the maximum rating of the machines connected to the bus. The percentage of reactance of alternators varies from about 8 per cent. to 30 per cent. The percentage reactance of transformers varies from about 3 per cent. to 30 per cent.

Breaker Application.—The problem of breaker application after the service voltage has been fixed is to determine the maximum current that may be encountered, and then the breaker should be chosen with an interrupting capacity equal to or greater than this maximum current.

Various formulæ for determining the increased rupturing capacity to be assigned to a breaker when it is used at less than its rated voltage have been offered but it is usual to convert the current rating into a K.V.A. rating at the listed voltage and then allow an increase in K.V.A. rating as the voltage is lowered.

The generally accepted method of rating is to estimate an increase in K.V.A. rating of 7½ per cent. at 75 per cent. of listed voltage, an increase of 15 per cent. at 50 per cent. of listed voltage and an increase of 22½ per cent. at 25 per cent. of listed voltage, all of these figures being contingent on the fact that the current calculated on this basis did not exceed a definite figure, determined experimentally, that expressed the maximum current that the breaker contacts could pass for 1 second or 5 seconds without danger of welding the contacts or causing mechanical distortion due to magnetic forces. While these figures differ somewhat with the details of design, they are usually given as 50 times normal for 5 seconds and in a few cases as 100 times normal for 1 second.

The rating of a circuit breaker in current interrupted at normal operating pressure simplifies the selection of a proper breaker for a given service condition.

Time of Tripping.—The time delay of oil circuit-breaker mechanisms has an appreciable effect upon the current which they will be called upon to interrupt under transient conditions. The contacts of ordinary oil circuit breakers part in from 0.05 to 0.40 seconds after the tripping circuit is energized, depending on the kind of operating mechanism and tripping methods used.

The data given for the selection of oil circuit breakers is applicable only to average systems. Therefore, a short discussion of other factors requiring separate or more detailed attention seems worth while.

Effect of Regulators.—When the alternators are equipped with automatic voltage regulators such regulators will increase the excitation after a short circuit in the endeavor to hold normal voltage on the bus bars. The maximum voltage which can be obtained from the exciters will be ordinarily not more than 50 per cent. greater than that required at full load 80 per cent. power factor on the alternators. Under short circuit, the alternator terminal voltage is reduced, hence the resultant flux density in the alternator iron is also reduced. A given increase in excitation, therefore, produces a proportionate increase in current flowing in the short circuit. Hence, as can be assumed, the excitation is increased 50 per cent., the sustained short-circuit

SHORT-CIRCUIT CURRENT FACTORS FOR THREE PHASE SYSTEMS

Method of tripping breaker corresponding to time elapsed		Elapsed time in seconds from time of short circuit	Reactance based on total KVA. rating of synchronous machines												
			8 %	10 %	12 %	15 %	20 %	30 %	40 %	50 %	60 %	75 %	100 %	125 %	150 %
			Current factors expressed as number of times full loss current												
No relay	A.C. series trip coil	0.05	13.91	11.16	9.59	7.68	6.04	4.03	3.01	2.40	2.00	1.58	1.17	0.92	0.77
	Cur. trans. with A.C. trip coil	0.08	11.78	9.54	8.25	6.66	5.27	3.59	2.74	2.21	1.86	1.50	1.13	0.90	0.76
Solenoid or motor relay	Cur. trans. with A.C. trip coil	0.10	10.94	8.89	7.63	6.23	4.97	3.41	2.63	2.13	1.81	1.46	1.11	0.89	0.76
	Cur. trans. with D.C. trip coil	0.15	9.16	7.54	6.57	5.40	4.83	3.02	2.42	2.00	1.71	1.41	1.09	0.89	0.76
Induction relay	Cur. trans. with A.C. trip coil	0.20	8.24	6.80	5.97	4.95	4.06	2.92	2.30	1.92	1.66	1.38	1.08	0.88	0.76
	Cur. trans. with D.C. trip coil	0.25	7.55	6.28	5.54	4.63	3.82	2.79	2.23	1.87	1.63	1.36	1.07	0.88	0.76
Circuit breakers having A.C. or D.C. trip with definite time setting.		0.30	7.03	5.88	5.19	4.39	3.67	2.70	2.18	1.84	1.60	1.34	1.06	0.88	0.76
		0.40	6.27	5.30	4.74	4.03	3.40	2.57	2.10	1.79	1.57	1.32	1.06	0.87	0.76
		0.50	5.74	4.91	4.40	3.80	3.23	2.48	2.04	1.75	1.54	1.31	1.05	0.87	0.76
		0.70	4.99	4.34	3.93	3.45	2.98	2.34	1.96	1.70	1.51	1.29	1.04	0.87	0.76
		1.00	4.25	3.77	3.47	3.11	2.73	2.21	1.88	1.65	1.48	1.27	1.04	0.87	0.76
		1.50	3.63	3.31	3.08	2.82	2.53	2.10	1.81	1.61	1.45	1.25	1.03	0.87	0.76
		2.00	3.20	2.98	2.82	2.63	2.39	2.03	1.77	1.58	1.43	1.24	1.02	0.87	0.76

current will be approximately 50 per cent. greater than the sustained current due to full-load 80 per cent. power factor excitation.

An appreciable time, however, is required for the excitation to increase to its maximûm value. During the first half-second the amount of short-circuit current is not affected by the presence of the voltage regulator but from this time on the current curve is higher, reaching the value at the end of 2 or 3 seconds of 50 per cent. greater than the current without the regulator.

An exception to the above appears when the external reactance is so high and the short-circuit current so limited that the regulator is able to maintain normal voltage at the generator terminals. In such cases the sustained current will be limited to the current which will pass through the external reactance with normal voltage impressed upon it.

Automatic Recommendations.—These are based on the assumptions that the breaker is in good operating condition and that its contacts will not part in less than the listed maximum time after the maximum instantaneous value of the abnormal current has been reached. Any faulty condition of the breaker, such as poor oil, stiff bearings, sluggish operation, or accumulation of dust will diminish its interrupting capacity. Also, if the contacts part in a shorter time than the listed minimum, a larger breaker will be required, while if the contacts part after a greater time than the listed minimum values, a smaller breaker may be used.

Time Relays.—These may be used to delay the parting of the oil circuit-breaker contacts after the start of the abnormal current. The greater the delay, the less, in general, will be the current to be interrupted. Hence by inserting a time delay relay, suitably adjusted, a given automatic oil circuit breaker may be used on a larger system, or for a given system, a smaller breaker may be used.

Short circuits in cables are not instantaneous in nature but develop gradually into dead short circuits. On such a short, a current may pass sufficient to actuate the breaker relay and develop into a dead short circuit at the time the breaker contacts open. Where full protection is required for such cases, a breaker good for the initial value of short-circuit current must be used.

Manufacturers' Guarantees.—The rupturing capacities assigned by manufacturers to their breakers are modified from time to time due to improvements in design, changes in materials employed and methods of manufacture used, but those given in this book are those that were considered correct by the manufacturers at the time of publication. These are, of course, subject to change by the manufacturers.

Direct Control.—The earliest electrical power plants containing a few machines of small output and moderate voltage were easily controlled from switchboards where all of the switches, meters, etc., were placed on panels. As voltage and output increased it became necessary to utilize more space for the switching devices and to operate them either by compressed air or by mechanical or electrical means from a central point.

Distant Control.—For the distant mechanical operation of oil circuit breakers American practice, with its oil switches usually designed for an up-and-down motion, favors the use of bell cranks and rods, the latter ordinarily being a piece of standard gas pipe screwed into suitable terminals attached to the bell cranks, operating handles, etc. As far as possible the different portions of the mechanical transmission are arranged in tension for closing the breaker to avoid bending stresses, although a reasonable amount of compression can be taken care of without unduly increasing the weight of the mechanism.

Manual Operation.—Manual closing from a cover plate lever or handle on a panel or frame bracket is the ordinary method of closing small or medium sized circuit breakers both panel mounting and remote control. With very large circuit breakers manual operation becomes impossible or undesirable, owing to the inability of a man to throw a large breaker fast enough for synchronizing purposes, or even to close the circuit breakers at all without excessive mechanical leverage, which is wasteful of space. Stresses in manually operated remote-control parts and the mechanical complication necessary to connect breakers located in positions inaccessible from the switchboard or control position, often preclude the use of manually operated remote control.

In the smaller sizes of manually operated remote-control circuit breakers, the automatic details are mounted directly in the cover plate, while in larger sizes the automatic latching details are located in a special operating mechanism mounted at the circuit breaker, thus taking the strain of the latch load off the panel and remote-control bell cranks and levers.

Where distance between switchboards and switching devices makes the application of hand operated breakers questionable, electrically operated breakers should be supplied.

Electric Control.—Most of this apparatus now in service is designed for use on a 125-volt direct-current circuit, although 250, 500 or any other available direct-current voltage can be used. In generating stations the exciter bus is sometimes the source of the direct-current supply, but where a voltage regulator is employed that causes the voltage of this exciter bus to fluctuate, it is often advisable to install a small storage battery in order to have a constant operating voltage. This battery is usually charged from one of the exciters, a small motor-generator set, or by using suitable resistances in series with a trolley circuit or other direct-current circuit.

Where, for any reason, it is not desired to install a battery and it is necessary to operate the devices from an exciter bus with fluctuating voltage, the solenoids or motors can be designed so that the variation in voltage will not materially change the pull of the solenoid or the speed of the motor.

In substations for D.C. service, the breakers, etc., are often designed for operation from the direct-current bus, and if the station has been completely shut down and no direct current is available, the first one or two breakers must be closed by hand. A small battery can often be used to advantage in such a station and it can be charged through a resistance from the D.C. bus. In transformer substations a small battery charged from a motor-generator set of about 5 K.W. capacity is nearly always installed.

A.C. Control.—From time to time it has been proposed to operate the various devices from alternating-current circuits, but the direct-current operation is so much cheaper and the additional complication due to its use is so small that alternating-current operation has made very little headway.

Indicators.—With any system of distant control apparatus, it is necessary for the operator to know whether the different pieces of apparatus have actually closed or opened or performed the function assigned to them. With manual operation the automatic opening of a breaker sometimes operates all of the mechanism back to the handle, so no other indication is needed, but in other cases the latch or toggle joint is at the breaker and the position of the handle gives no clue to the position of the breaker. For such cases or where an auxiliary source of power is used for operating the devices some very ingenious methods of signalling have been designed. For a breaker of any sort a mechanically operated switch is usually provided and this switch is thrown from one position to the other by the movement of some part of the mechanism of the main breaker. A certain amount of lost motion is usually provided so that unless the breaker goes all of the way in or out the position of the signal switch is not altered. From these signal switches circuits are run back to the switchboard to operate signal lamps or similar devices. These lamps are often arranged to form part of a miniature bus circuit to show the connections that have been made by the breakers.

In the field of power operated oil circuit breakers other than the 'H' line of G.E. oil breakers, electrical-solenoid method of closing is now used almost universally to the exclusion of various other methods, such as motor, hydraulic, and pneumatic power. The electric-solenoid type of operation is very flexible and permits mounting the operating mechanism on cell walls, or pipe frames, or on the floor above or below, or behind the circuit breaker.

Electric operating mechanisms are usually provided with combined accelerating and dashpot attachments, the former to insure speedy opening of the contacts on tripping, the latter to dissipate the kinetic energy of moving parts on the end of the opening stroke. They are also usually equipped with dashpots under the closing cores to absorb shocks of moving parts in closing. The action of these dashpots is regulated by adjusting screws, which determine the extent of the valve opening.

Control Circuit.—Standard electric operating (closing and tripping) mechanisms are made for direct-current operation. This form, besides utilizing simpler construction, being more reliable in operation, and more easily kept in repair, is much more economical of space and power than alternating-current mechanisms. For special applications, such as for alternating-current electrically operated railway sectionalizing circuit breakers and other installations where no auxiliary source of direct-current power is available, special alternating-current operating mechanisms can be supplied.

Mechanism.—The standard electric mechanism closes the breaker by a direct-current magnet and holds it closed by a latch and trigger or a toggle, which engage automatically. The tripping mechanism consists of a direct-current trip magnet acting on a trigger which releases the latch, permitting the breaker to open.

The closing and tripping mechanism is operated by a control switch, with or without control relays (switches) in the closing circuit, and usually with signal lamps.

All electric operating mechanisms have a small double-throw switch to open the shunt-trip coil circuit when the circuit breaker opens and to operate the signal lamps.

Control Voltage.—The standard electric mechanisms are regularly supplied with closing solenoids wound for 70 to 140 volts (110 volts nominal) direct current. The time required to close a breaker from the time of the closing of the control switch contacts until the arcing contacts in the breaker touch, is $\frac{3}{10}$ to $\frac{6}{10}$ seconds. Coils for other than the aforementioned standard voltages, or of greater operating range, can be supplied.

The electric mechanisms are equipped with tripping as standard, to operate at from 50 to 140 volts direct current.

Electric operating mechanisms can be furnished with closing coils to operate at from 140 to 280 volts, direct current, or to trip at from 100 to 280 volts, direct current.

Acceleration.—One of the prime necessities in oil circuit-breaker operation is that when the contacts have commenced to separate they shall travel rapidly, especially during the first part of the stroke. Speed of operation reduces the duration of the arc, reduces the amount of energy expended in the arc, reduces the volatilization of metal parts and oil, and, consequently, reduces the tank pressure which is a determining factor in the ultimate capacity rating of a breaker. All small automatic circuit breakers are provided with accelerating springs in the contacts themselves, which insures speedy operation when the switch is unlatched. Automatic overload-trip remote-control circuit breakers in smaller sizes are provided with accelerating devices mounted on one of the remote-control bell cranks. This device precludes any possibility of the sticking of the circuit breakers, when tripped, in case the system of remote-control rods and cranks is arranged so that they over balance the weight of the circuit breaker contacts; it also insures a rate of acceleration of moving parts greater than that due to unassisted gravity. Where the weight of the moving contact parts is large and there would be danger of breakage if they were suddenly arrested, the device is equipped with means of stopping the moving contact.

The beneficial effect on the operation of a circuit breaker by this accelerating device is such that a remote-control circuit breaker often can be rated at a higher breaking capacity than the corresponding panel mounting circuit breaker.

METHODS OF TRIPPING

Non-automatic Trip.—Manually operated circuit breakers, supplied for non-automatic operation, are tripped by hand from the faceplate or breaker mechanism. Electrically operated circuit breakers supplied for non-automatic operation are supplied with a direct-current shunt-tripping magnet acting on a trigger that releases the latch. The shunt-tripping magnet is usually energized by a circuit controlled from some central point, or it may be connected to a relay circuit, thus giving automatic features through the relays.

When direct current is not available for operating the standard shunt tripping magnet, special magnets can usually be supplied for using alternating current.

Automatic Overload Trip.—Plain-automatic overload-trip circuit breakers when closed with an overload on the line will remain closed as long as the closing coil (of electrically operated breakers) is energized, or the manually operated mechanism is held in the closed position. With electrically operated breakers, when the closing coil circuit is opened, the breaker will not remain closed on overloads. Electrically operated circuit breakers, only, are regularly supplied plain automatic.

Full Automatic.—Full-automatic overload-trip circuit breakers have a mechanism making it impossible to hold the breaker in a closed position while a continuous overload condition or short circuit exists on the circuit.

Transformer Trip.—For manually operated circuit breakers direct tripping from the secondary of current transformers is the most common method of automatic overload tripping where no time element feature is necessary. For some low voltage indoor circuit breakers, series trip overload coils can be used, mounted directly on the circuit breaker.

Where time limit features are wanted, inverse time limit dashpots are supplied on some types of circuit breakers, or relays having this feature may be used.

For electrically operated circuit breakers, tripping from the secondary of current transformers is most common. This tripping can be accomplished by connecting the secondaries directly to the current trip coils of the circuit breaker, or by connecting them to relays which operate the current trip coils or shunt-trip coils. Series automatic overload-trip coils can also be used on some electrically operated circuit breakers.

The coils for current transformer automatic overload trip are mounted in the cover plate or on the breaker mechanism of the manually operated circuit breakers, and on the operating mechanism of electrically operated circuit breakers.

Ordinarily, where current transformers are used for instruments and watt-hour meters the trip coils can be connected to the same transformers, if great accuracy is not required. Where not required for instruments or meters, lower priced transformers of good accuracy are available for connection directly to the circuit-breaker trip coils or to relays.

Series Trip.—The coils for series automatic overload trip are either dry insulated, mounted in the switchboard cover plate, or they are contained in the circuit-breaker oil tank. In the former case, the main connections to the series trip coils are made through holes in the panel, these holes being covered by the cover plate. This method of trip is recommended to be applied only to small low capacity installations not having current transformers for meters.

Tripping Calibration.—Breakers automatically operated from current transformers and current transformer trip coils or from series trip coils are usually calibrated to function through a range of from 80 to 160 per cent. of the normal current rating of the current transformer or of the series trip coil. The tripping coils can be set to function at any current within the range given on the scale. Since the transformer trip coils are energized by power from the secondaries of series transformers in the main circuit, the high voltage is removed from the cover plate and, therefore, from the front of the switchboard panel or other operating station.

Inverse Time.—When inverse time limit is required to prevent the circuit breaker coming out unnecessarily on short overloads, an adjustable inverse time limit dashpot can be applied to the standard cover plate of some breakers, With various mixtures of oil, the time limit can be varied considerably.

Where automatic undervoltage protection is required or where tripping is desired upon failure of power rather than from an auxiliary circuit, an automatic undervoltage trip can be supplied. Up to 600 volts alternating current the coil of this attachment is shunted directly across the line but on higher voltages the coil is connected in the secondary of a voltage transformer.

The automatic undervoltage-trip attachment, as described above, can be supplied with a 5-ampere coil and then used as an automatic underload-trip device in connection with appropriate current transformers to trip the circuit breakers upon the load decreasing below a predetermined amount. These are of the manual reset form.

Automatic overvoltage-trip coils can be used on circuit breakers to trip the breaker in case the voltage of the circuit increases to a certain predetermined setting.

CONDIT OIL CIRCUIT BREAKERS

A very complete line of oil circuit breakers has been put on the market by the Condit Electrical Manufacturing Company, of South Boston, ranging in size from the types G, I and N for industrial service and motor starting, the M for manhole and P for pole top through the various switchboard types E and D to the large capacity separately mounted breakers for compartment mounting and the outdoor high tension breakers.

Motor Starters.—The type G-1 oil motor starters are used for starting squirrel-cage motors that do not need any auto starter or compensators. These are essentially double-throw breakers for currents up to 100 amperes for motors up to 35 H.P. In the starting position the overload coils are not in circuit but as soon as the motor gets up to speed the breaker is thrown over to the running position when the automatic coils are cut in and time limit devices prevents a momentary current surge from tripping out the breaker.

The type I motor starters are somewhat similar but in place of overload coils the automatic protection is secured through fuses that are cut out at starting but in circuit during the running position. These are used for motors up to 10 H.P. at 440 and 550 volts.

The N-1 oil starter is suitable for circuits with starting currents up to 150 amperes at 110 volts, 80 amperes at 550 volts. Its general features correspond with the G-1.

Entrance Switches.—The N-2 oil circuit breakers are intended principally as entrance switches for a maximum current of 60 amperes and maximum voltage of 600. The case is divided into three parts: the top contains the fuses; the middle carries the switch mechanism; the bottom forms the oil tank. While this is a non-automatic device with or without fuse clips it can be provided with shunt-trip or undervoltage release.

Manhole Switches.—For manhole service the M-5 is furnished both single throw and double throw with cable sleeves for single conductor cable and the M-6 is furnished for single throw only and for multiple conductor cables. The design of the operating mechanism of the M-5 and M-6 oil switches embodies the highly important feature of easy closure, and at the same time affords ample pressure at the contact surface. It is extremely simple in design and positive in action. The bearings are made of non-corrosive metal. The handle not only operates the switch, but, being removable, also serves to insert and remove the plug which seals the switch. Each brush or bridging member is built of special hard-drawn copper laminæ, so formed that each lamina makes individual contact with the stationary contact member and allows a definite space for the free circulation of oil between adjacent laminæ. The brushes make contact with a long-wiping, self-cleaning action. They are secured to specially treated wood rods in such a manner that they are self-aligning, insuring each individual lamina carrying its full share of the current. This construction gives the laminated brush decidedly excellent current-carrying features. Each brush is protected by two auxiliary arcing tips made of relatively heavy, special shaped, hard-drawn copper. They are mounted on the extremities of a spring support fastened to the lower portion of the brush so as to make contact with similar stationary arcing tips fastened to the stationary contact member. Each of these arcing tips is easily renewable and reversible, giving approximately twice the usual length of service, and decreases the maintenance cost of the switch correspondingly.

Pole Switches.—Pole line oil switches, type PK-5, are for weatherproof service and are used for the sectionalizing of lines, switching of transformer banks and similar service. They are suitable for use on alternating-current circuits where the current does not exceed 200 amperes at pressure of 4500 volts or less.

The mechanism is extremely simple in construction and is enclosed in a substantial weatherproof iron case. The cover is provided with an overhanging rim, securely fastened by swinging bolts and wing nuts, permitting easy access to the interior. A depending projection on the front of the cover serves as an efficient watershed for the operating handle and prevents the formation of ice and sleet from interfering with the operation of the switch.

The oil tank is made of heavy sheet metal with welded joints, combining strength and rigidity, and is fastened to the frame by means of swinging bolt and wing-nut construction, thus allowing the tank to be readily removed without disturbing any of the operating parts.

The tank is provided with a suitable lining, and barriers are interposed between the poles to give additional protection against arcing under severe conditions.

Single-tank Breakers.—The E line of breakers is distinguished by having all poles of the breaker in the same tank. The E-3 breakers are arranged for panel mounting, panel frame mounting or remote control by hand or solenoid. Series trip coils or current transformer trip can be used and a rupturing capacity of 1600 amperes at 4500 volts, 3300 at 2500 can be guaranteed.

Type E-3.—Condit type E-3 oil circuit breakers, Fig. 55, have been designed primarily for controlling and protecting feeder circuits, transformer banks, generators, etc., where moderate interrupting capacity is required. They are made in two, three and four poles, single and double throw, automatic and non-automatic, for manual and electrical operation. All of the automatic forms may be provided with undervoltage, shunt-trip and time limit attachments. Auxiliary switches of the circuit opening and circuit closing type may also be utilized in connection with either the non-automatic or automatic form.

The automatic form may be furnished in either series,current transformer, or relay trip. Type E-3 series trip oil breakers have a maximum capacity of 200 amperes, and may be used where the pressure does not exceed 2500 volts.

Non-automatic and current transformer or relay trip oil circuit breakers are furnished in capacities up to and including 300 amperes, and may be used where the pressure does not exceed 4500 volts. They are furnished for panel, panel frame or pipe frame mounting for direct control, and are arranged for flat surface or pipe frame mounting for manual remote control or electrical remote control. Double-throw switches and circuit breakers are arranged for panel mounting only.

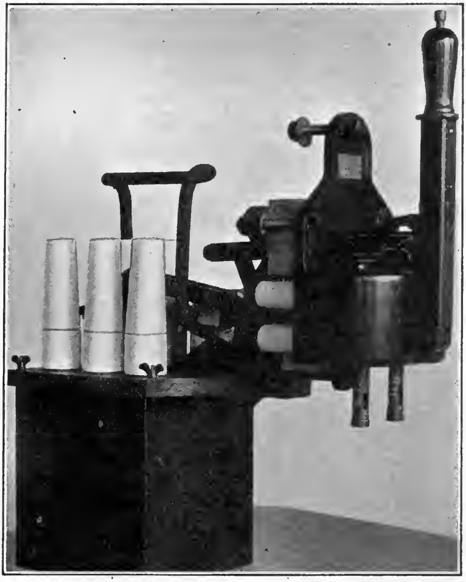


Fig. 55.—Condit Electric & Mfg. Co. oil circuit breaker, type E3, single throw.

All automatic type E-3 overload circuit breakers have their trip coils and calibration adjustments on the front of the switchboard, and the mechanism is arranged to prevent the operator from holding the switch closed during an overload or short circuit. The mechanism is capable of adjustment to suit the conditions of installation.

Studs.—The studs are copper rod of sufficient cross-section to properly carry their rated current continuously, and are insulated from the frame by high-grade, well-glazed porcelain bushings, thus affording ample insulation. The top of the stud is threaded to receive the terminal to which line conductors may be connected. Fastened to the lower end is a stationary contact member on which is mounted the stationary arcing tips.

The terminals are enclosed in an insulating sleeve in order to prevent accidental contact with the live parts.

Tank.—The oil tank is made of heavy sheet metal with welded joints, combining strength and rigidity. The tank fits inside of an overhanging rib which forms a part of the cover or frame of the breaker. This rib construction materially reinforces the tank and prevents its sides from bulging outwards, even when subjected to excessive pressure from within. It is fastened to the cover or frame by means of heavy tank bolts and wing nuts, thus allowing the tank to be readily removed for inspection, without disturbing any of the operating parts. The tank is provided with a suitable lining and barriers are supplied between the poles to give additional protection against arcing under severe conditions. An oil line on the outside of the tank indicates the height to which the tank should be filled with oil when removed from the breaker.

Fig. 56.—Condit Electric & Mfg. Co. oil circuit breaker, type E4, double throw.

Type E-4.—Fig. 56 shows the arrangement of the panel mounting, double-throw breaker, with the two interlocked closing handles. These type E-4 breakers are made in capacities of 300 and 500 amperes at 7500 volts and 800 at 4500 for rupturing capacities of 1700 amperes at 7500 volts for the 300 and 500 ampere sizes, 3160 at 4500 for all sizes, 6100 at 2500 for all sizes, and 15,000 for the 300 and 500 at 750, and 20,000 at 750 for the 300 ampere size. Their general features correspond closely with those described for the E-3.

All automatic type E-4 overload circuit breakers have their trip coils and calibration adjustments on the front of the switchboard, and the mechanism is arranged to prevent the operator from holding the switch closed during an overload or short circuit.

Fig. 57 shows the arrangement of the 800-ampere 4500-volt type E-4 breaker hand operated, remote control.

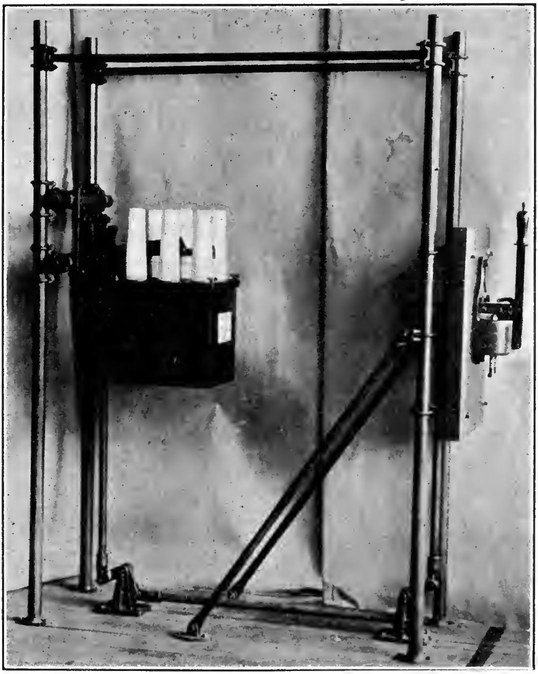


Fig. 57.—Condit Electric & Mfg. Co. oil circuit breaker, type E4, hand operated, remote control.

Motor Starters.—The type E-6 oil starter is a combination of a switch and a circuit breaker, used for controlling and protecting induction and self-starting synchronous motors whose continuous full-load current, including overloads, does not exceed 200 am peres at pressures of 2500 volts or less.

They are used extensively for starting squirrel-cage induction motors without the use of auto transformers or compensators.

Three-pole switching equipment is furnished for use with 3-phase or 3-wire, 2-phase induction motors, and 4-pole switching equipment is furnished for use with 2-phase motors supplied from 4-wire, 2-phase, non-interconnected systems. Type E-6 oil starters are made 3 or 4-pole, manually operated, panel mounting only, arranged for series or current transformer trip with time limit attachments and selective mechanical interlock. They may also be provided with under-voltage and shunt-trip attachments.

The faceplate is provided with two handles. The handle on the left operates the starting switch and cannot be latched closed. The handle on the right operates the circuit breaker which protects the motor, when running, from short circuit, overload, and single phase running.

The trip coils and calibration adjustments are conveniently located on the front of the panel.

Type E-7.—The type E-7 oil starter is a combination of a switch and a circuit breaker, used for controlling 3-phase induction or self-starting synchronous motors whose continuous full-load current, including overloads, does not exceed 200 amperes at pressures of 2500 volts or less. These oil starters are arranged only for 3-wire, 3-phase, and 3-wire, 2 phase, alternating current motors. They are not suitable for use on 4-wire, 2 phase, non-interconnected systems. They may be used in connection with auto transformers having either 2 or 3 exciting coils, and are made 4-pole, manually operated, panel mounting only, arranged for series or current transformer trip with time limit attachments and selective mechanical interlock. They may also be provided with undervoltage and shunt-trip attachments.

The faceplate is provided with two handles. The handle on the left operates the starting switch and cannot be latched closed. The handle on the right operates the circuit breaker which affords protection against short circuit, overload and single-phase running.

Independent Tank Breakers.—Type D-12 circuit breakers have independent tanks for each pole of the breaker but all poles on the same frame. These breakers have a guaranteed rupturing capacity of 1250 amperes at 15,000 volts; 2500 at 7500; 4200 at 4500, and 7500 at 2500 volts. The 300, 500 and 800 amperes at 2500 volts are made for panel frame mounting and all of the other ratings for distant control only. They are used to meet the demands in controlling and protecting electrical circuits and apparatus where the pressure does not exceed 15,000 volts. They are well adapted for installations where space requirements are an important factor, and a relatively high interrupting capacity is desired. They are used principally to control feeder circuits in substations of large distribution systems

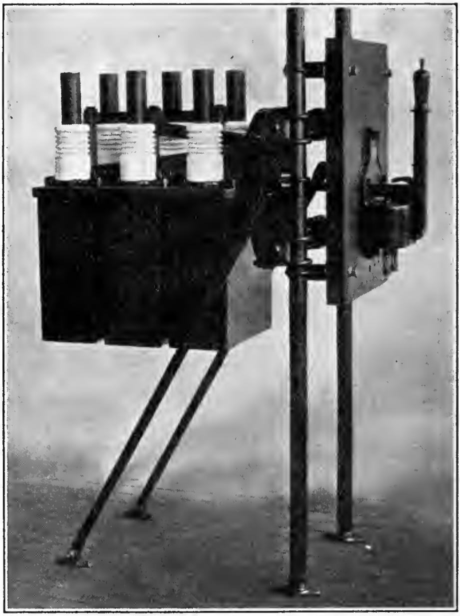


FIG. 58.—Condit Electric & Mfg. Co. oil circuit breaker, type D12, frame mounted.

and for the control and protection of generators and feeders in industrial service where a relatively high rupturing capacity is required at moderate voltages.

All automatic type D-12 overload circuit breakers have their trip coils and calibration adjustments on the front of the switchboard, and the mechanism is arranged to prevent the operator from holding the switch closed during an overload or short circuit. They are furnished for current transformer trip or non-automatic, as panel frame mounting shown in Fig. 58, 2500 volts or less where the current does not exceed 800 amperes. For flat surface (wall or cell mounting) or for pipe frame mounting, they can be supplied manually operated remote control and electrically operated for 4500 volts or less where the current does not exceed 1200 amperes; 7500 volts or less where the current does not exceed 1000 amperes; 15,000 volts or less where the current does not exceed 800 amperes.

Electrically operated.—This type of D-12 oil circuit breakers, Fig. 59 is furnished in the standard ampere capacities, poles, and mountings at the various voltages. They consist of the

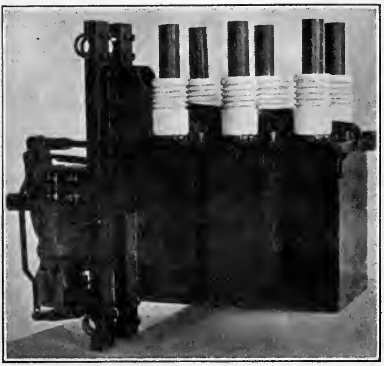


Fig. 59.—Condit Electric & Mfg. Co. oil circuit breaker, type D12, solenoid operated, 1200 amps.

standard manually operated breaker equipped with a closing magnet, opening magnet, control relay, control switch with red and green indicating lamps, and one indicating lamp switch.

Terminals up to and including 800 amperes are enclosed in an insulating sleeve to prevent accidental contact with live parts. Circuit breakers in excess of 800 amperes are provided with laminated terminals to which cable terminals or flat copper connections may be bolted.

Each pole of the D-12 oil circuit breakers is provided with an individual oil tank made of $\frac{1}{8}$-inch steel with welded seams, and is provided with a suitable lining. Each tank is fastened to the frame by a strong tank bolt construction, which allows ready removal for inspection without disturbing any of the operating parts.

A depending flange, which serves to strengthen the frame, prevents any tendency to tank distortion when circuit breakers are called upon to interrupt the circuit under severe conditions. An oil line on the outside of each tank indicates the height to which the tank should be filled with oil when removed from the breaker.

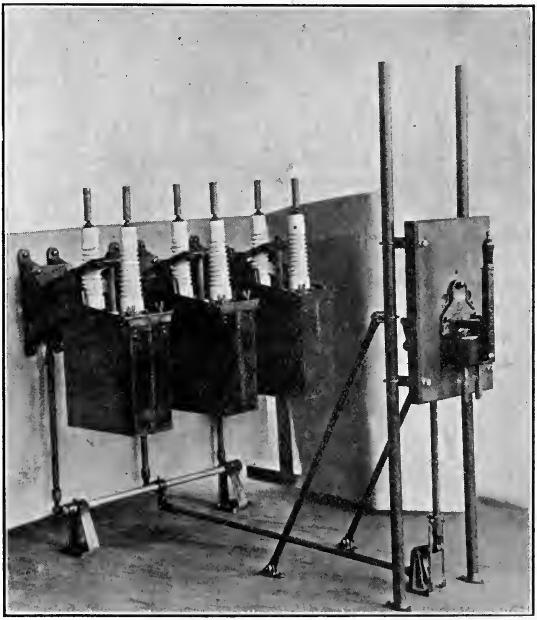


Fig. 60.—Condit Electric & Mfg. Co. oil circuit breaker, type D13, hand operated, remote control.

Type D-13.—The D-13 oil circuit breakers have a guaranteed rupturing capacity of 1000 amperes at 25,000 volts for the 300 and 500 ampere sizes; 1700 at 15,000, 3500 at 7500, 5800 at 4500, and 10,000 at 2500 for all sizes. They are made in single, 2-, 3-, and 4-poles, for manual remote control or electrical operation with separate tanks per pole. They are furnished in 300, 500 and 800-ampere capacity for pressures of 15,000 volts or less, and for capacities of 300 and 500 amperes where the pressure does not exceed 25,000 volts. This type is adapted for flat surface mounting on either walls or in cells, or it may be mounted on pipe frame structures.

Mechanism.—Each pole of the D-13 oil circuit breakers, Fig. 60, is provided with an operating mechanism of unique design. The upper extremity of the brush rod is provided with a threaded ferrule fastened so as to give maximum mechanical strength. The ferrule and rod are threaded into a pivoted cross-head at the end of the operating mechanism which travels with a straight-line motion. This construction serves as a brush adjustment and maintains the brush rigidly in its proper position in relation to the stationary contact members. The brush is fastened in a self-aligning manner to the lower extremity of the brush rod.

The mechanism closes easily and at the same time affords ample pressure at the contact surface. It is designed particularly to allow rapid acceleration of the movable contact members during the initial opening of the circuit. Each of the individual poles is operated through a common shaft, which may be actuated either manually or electrically.

Attachments.—Undervoltage attachments for D-12 and D-13 breakers are designed so that the breakers will be released when the pressure drops to approximately 50 per cent. of its normal value. Shunt-trip attachments are provided with a heavy tripping spring, which insures positive action. They are wound for voltages of 110, 220, 440, and 550, for either direct or alternating current, 25 or 60 cycles, and have an operating range from 55 to 115 per cent. normal voltage.

Many forms of devices, such as relays and time limit attachments, may be used in conjunction with type D-12 oil circuit breakers for the purpose of causing their operation in accordance with predetermined conditions. Type D-12 oil circuit breakers may be furnished with time limit attachments applied directly to the calibration tubes, in capacities up to and including 800 amperes. Time limit attachments are not furnished for 1000 amperes and above.

Heavy-current Types.—Type Y-1 and Y-2 oil circuit breakers are used on circuits of moderate voltage and relatively large ampere capacity, for the control and protection of generators,

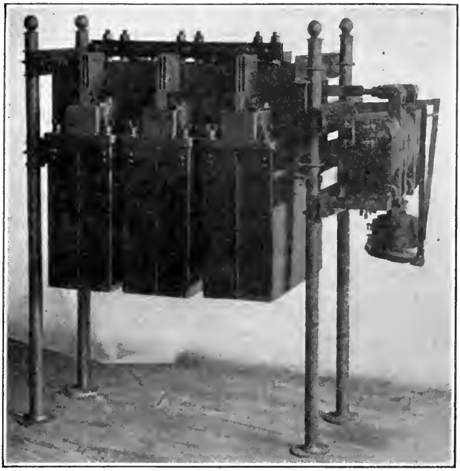


Fig. 61.—Condit Electric & Mfg. Co. oil circuit breaker, type Y1.

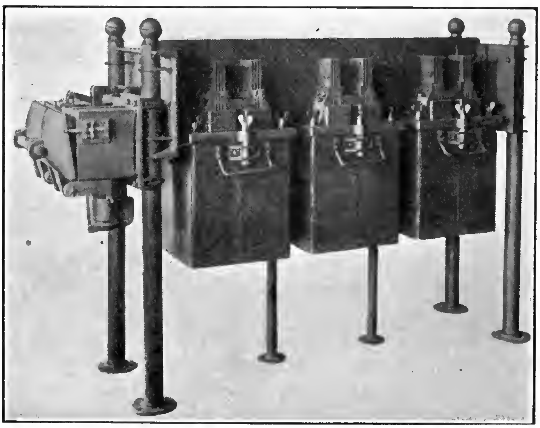


Fig. 62.—Condit Electric & Mfg. Co. oil circuit breaker, type Y2.

motors, transformer banks, feeder-circuits, as service entrance switches, etc.

Type Y-1.—These oil circuit breakers as shown in Fig. 61 are made 3 and 4-pole, automatic and non-automatic, for manual remote-control and electrical remote-control operation. All of the automatic forms may be provided with undervoltage and shunt trip. They are furnished for use on circuits where the pressure does not exceed 2500 volts and the current does not exceed 2500 amperes at 60 cycles, or 3000 amperes at 25 cycles.

Type Y-2.—These oil circuit breakers, Fig. 62, are made 3-pole only, for use on circuits where the pressure does not exceed 2500 volts, and where the maximum capacity does not exceed 4500 amperes at 60 cycles, or 5500 amperes at 25 cycles. Auxiliary switches of the circuit opening and circuit closing type may be utilized in connection with either the automatic or non-automatic forms.

Ratings.—The Y-1 breakers are made in 25-cycle ratings of 1800, 2400 and 3000, amperes with corresponding 60-cycle ratings of 1500, 2000, and 2500. The Y-2 breaker has a 60-cycle rating of 4500 amperes and a 25-cycle rating of 5500. The guaranteed rupturing capacities of the Y-1 are 7500 amperes at 2500 volts, 30,000 at 750, while for the Y-2 the rupturing capacities are 15,000 at 2500 volts, 50,000 at 750.

Each pole of the type Y oil circuit breakers is provided with an individual steel oil tank with welded seams. Each tank is fastened to the frame by a strong tank bolt construction which allows ready removal for inspection without disturbing any of the operating parts.

A rugged, box-shaped frame carries the operating mechanism, to which is securely fastened a heavily ribbed, non-magnetic metal cover which serves as a support for the insulating bushings, studs and oil tanks.

Brushes.—Each brush or bridging member, shown in Fig. 63 is built up of special hard-drawn copper laminæ, so formed that each lamina makes individual contact with the stationary contact member and allows a definite space for the free circulation of oil between adjacent laminæ. The brushes make contact with a long-wiping, self-cleaning action. Each brush is suspended by an individual, specially treated wood rod, in such a manner that the brushes are self-aligning in relation to the stationary contact members. This construction permits of easy and convenient individual brush adjustment, without the use of shims—a feature of great importance in apparatus for this class of equipment.

The studs are insulated from the supporting frame by moulded insulation designed particularly to withstand mechanical strains incident to the operation and installation of oil circuit breakers of large ampere capacity. The studs are made up of laminated copper bars, each 4-inch by ¼-inch, the number depending upon the ampere capacity. The top of the stud is arranged to receive ¼-inch bar connections or cable terminals to receive the line conductors. Fastened to the lower end of the stud is the stationary contact member on which are mounted the stationary arcing tips.

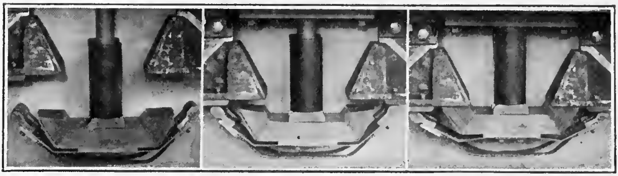


FIG. 63.—Condit Electric & Mfg. Co. brush construction type "Y2" oil current breaker.

Each brush unit is protected by two extra heavy, special-shaped auxiliary arcing tips made of hard-drawn copper. They are mounted on the extremities of a spring support fastened to the lower portion of the brush, so as to make contact with similar stationary arcing tips. Each of these arcing tips is easily renewable and reversible, giving approximately twice the usual length of service and decreasing the maintenance cost correspondingly.

Cell Mounting.—The type F-6 oil circuit breakers, Fig. 64, are furnished 3-pole only, cell mounting, in 500 and 800 ampere capacities where the pressure does not exceed 15,000 volts. They may be arranged for either hand remote control or electrical operation and embody distinctive features which make them highly desirable for installations where continuity of service is essential.

Construction.—The renewable unit construction is employed in connection with the type F-6 oil circuit breaker, as this renders the quickest possible means of replacement, repair or inspection. The operating mechanism is entirely enclosed in the expansion chamber, which is firmly fastened to a ¼-inch steel tank supported on a three-point truck to facilitate easy handling. The electrically operated mechanism is compact, of simple design, and is mounted above the switch units. The conductors may be brought to the circuit breaker either through the top or rear of the cell.

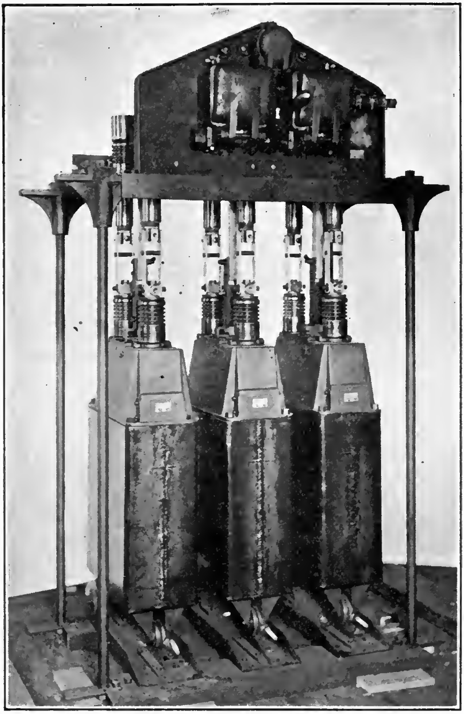


Fig. 64.—Condit Electric & Mfg. Co. oil circuit breaker, type F6.

The important features of design which characterize the type F-6 oil circuit breakers are the efficient laminated brush, reversible and easily renewable arcing tips, self-aligning, sure seating action between the movable contact members and the stationary contact members, the rugged tank-per-pole construction,

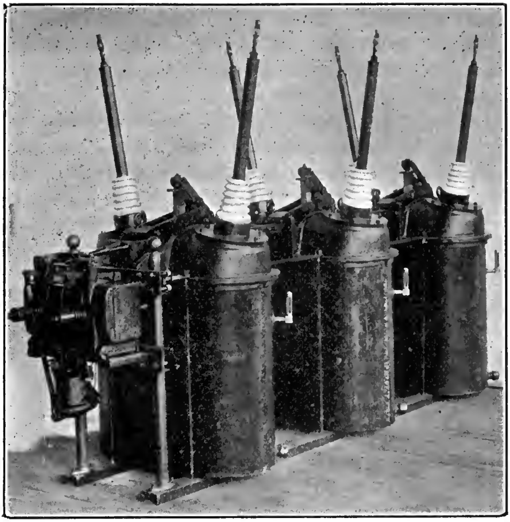


Fig. 65.—Condit Electric & Mfg. Co. oil circuit breaker, type D15 floor mounting.

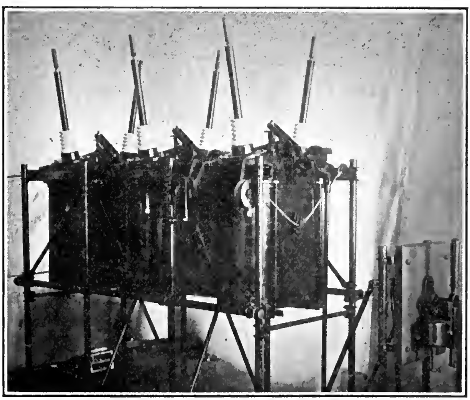


Fig. 66.—Condit Electric & Mfg. Co. oil circuit breaker, type D15, frame mounting.

high head of oil over break, large expansion chamber and the strong spring action inherent in the brushes which facilitates rapid acceleration of the movable contact members on the initial opening of the circuit.

High Voltage Breakers.—Type D-15 oil circuit breakers are furnished for indoor application for the control and protection of transmission lines, transformer banks, etc., where the normal operating voltage is 44,000 volts or less. The type R-1 oil circuit breakers are used where the normal operating voltage is 70,000 volts or less. For outdoor application, type D-16 oil circuit breakers are furnished.

Type D-15.—These oil circuit breakers are made 3-pole only, arranged for manual direct control, manual remote control or electrical remote control. They are furnished in the following standard ampere capacities: 300 amperes, 44,000 volts or less; 300, 500 and 800 amperes, 25,000 volts or less. They are made in two forms of mounting: floor mounting, where the tanks rest on the floor, as shown on Fig. 65 and frame mounting, as shown on Fig. 66.

They consist essentially of three separate, identical units, sufficiently spaced so that cell walls and barriers are usually unnecessary. Each unit consists of a strong, well ribbed cover, forming a large expansion dome. This cover supports the mechanism and conducting parts. The oil tank is securely fastened to the expansion dome, and is provided with an oil gauge and oil drain.

The D-15 oil circuit breakers are characterized by the laminated brush, reversible and easily renewable arcing tips, the rugged tank construction, large expansion chamber, and the strong spring action of the brushes which facilitates rapid acceleration of the moving contact members upon the initial opening of the circuit. They are furnished for current transformer and relay trip.

Type D-16.—These oil circuit breakers are furnished for outdoor application for the control and protection of transmission lines, transformer banks, etc., where the normal operating voltage is 44,000 volts or less. They are made 3-pole only, arranged for manual direct control or electrical remote control and are furnished in the following ampere capacities: 300 amperes 44,000 volts or less; 300, 500 and 800 amperes, 25,000 volts or less.

The D-16 oil circuit breakers are made in two forms of mounting: floor mounting, where the tanks rest on the floor, and frame mounting, Fig. 67, where the tanks are supported by a frame structure. They consist essentially of three separate, identical units, so arranged with relation to a common operating mechanism as to cause simultaneous operation of the contact members. Each unit consists of a strong, well ribbed cover, forming a large expansion dome. This cover supports the mechanism, bushings and weatherproof hood. The oil tank is securely fastened to

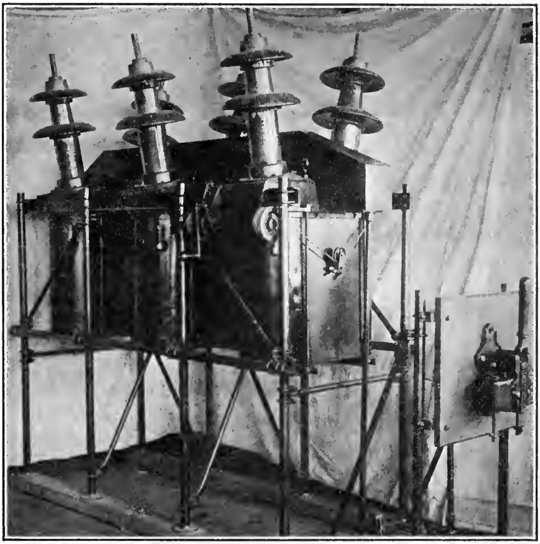


Fig. 67.—Condit Electric & Mfg. Co. oil circuit breaker, type D16, frame mounting.

the expansion dome and is provided with an oil gauge and oil drain. These oil circuit breakers are characterized by large expansion chamber with baffled gas vents, substantial tank construction, reversible and easily renewable arcing tips, and efficient laminated brush, the strong spring action of which facilitates rapid acceleration of the moving contact members upon the initial opening of the circuit.

GENERAL ELECTRIC OIL BREAKERS

The General Electric Company early advocated the use of the oil circuit breaker for A.C. service and have done a great deal of pioneer work in developing breakers suitable for various classes of service. Their earlier designs have naturally been superseded by later modifications embodying the improvements that experience has shown to be advantageous.

Lines.—There are a number of different lines of breakers to take care of the different classes of work. For the small industrial service, there are the 'FP-10' and similar breakers; for the moderate capacity moderate voltage breakers for switchboard service the 'K-5' and 'K-12' breakers are being superseded by the 'K-32' and 'K-35,' while for moderate voltages and high rupturing capacity the 'H-3,' 'H-6,' and 'H-9' breakers are utilized and the high voltage circuits are taken care of by the 'K-24,' 'K-26,' 'K-36,' etc.

Industrial.—For industrial service the 'FP-10' breaker is built in capacities up to 50 amperes for 600 volts, is arranged for conduit wiring and is suitable for induction motors up to 25 H.P.

The automatic breaker is provided with two series inverse time overload trip coils, mounted inside the cover. Dashpots and calibrating tubes are covered by a drawn steel casing attached to breaker frame. The breaker cannot be held closed on overload or short circuit. The undervoltage breaker can be furnished triple or four-pole with a self-setting undervoltage release attachment mounted inside the breaker frame which trips the breaker if the voltage of the line drops to approximately 50 per cent. of normal.

The non-automatic breaker is similar to undervoltage and overload forms except there is no tripping attachment and operating mechanism is slightly different.

The combined overload and undervoltage breaker is made triple-pole with undervoltage release and overload protective plugs; four-pole with undervoltage release and double-series overload trip. Both protective plugs and series coils with time delay provide protection to motor when starting. Four-pole breaker is used triple-pole by omitting connections to one set of contacts.

The cover is a single piece of sheet steel and fits tightly over the top of the breaker frame which is a light but strong sheet-steel box which supports all parts of the breaker. The words "off" and "on" on the frame indicate whether the breaker is open or closed. Oil dashpots give time delay to automatic overload trip which can be set to remain inactive on starting current of motor but to trip out breaker on sustained overloads, including those caused by single-phase operation.

The operating handle is the only movable part of breaker not enclosed. On opening this form of breaker manually, the handle is moved some distance to the left before the contacts begin to part, after which they are snapped quickly open by a torsion spring on the operating shaft.

The fixed contacts are copper fingers flared at lower end to form arcing tips. Contact studs are securely held in a porcelain block.

The movable contacts are mounted in a porcelain block, and consist of copper strips bent to form. The arc, on opening breaker under load, is confined to the stationary arcing tips and upper ends of movable contacts, and does not affect the working contact surfaces. Contacts are always kept clean and will last a long time even under rough usage.

All combinations, both automatic and non-automatic, except the triple-pole, plain undervoltage breaker and the combined undervoltage, protective plug breaker can be furnished either with the quick break, or quick make and quick break mechanism. Quick break is a feature of all these breakers. Breakers with both quick make and quick break mechanism are especially adapted for shipper rod operation.

Textile.—A modification of this breaker known as the 'FP-15' is made for non-automatic service, particularly for motors on textile machinery, and the operation is either manually or by shipper rod. They can be used to great advantage to replace knife switches as their safety features make the breaker dust-proof and fireproof as well as guarding the operator.

Pole Line.—For pole line service the 'FP-7' is intended for mounting on any vertical flat surface and is supported on the side opposite the operating handle. The frame is a cast-iron box which supports all parts of switch and is provided with a cast-iron cover fastened to frame by four eye bolts with wing nuts. Porcelain entrance bushings are used for all cables entering the switch. The fixed contacts are drop-forged copper fingers flared at lower end to form arcing tips while the movable contact blades are wedge-shaped, which confines arc to top edge of blade and flared portion of contact fingers. The oil vessel is made of heavy sheet metal lined with laminated wood and barriers of same material between poles.

Old K-5 and K-12.—Some of the older designs of type 'FK-5' and 'FK-12' were built with insulators suitable for 15,000 volt service for the 500-ampere size, this being modified by using shorter porcelains with extension pieces under the oil to utilize the same moving parts and to secure the same depth of oil over the contacts for 2500-volt service, and for 600-volt service. The rupturing capacities assigned to the FK-5 for their various voltages were 1700 at 7500, 2600 at 4500, 5300 at 2500 and 15,000 at 600 volts.

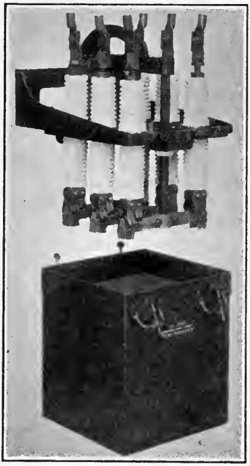


Fig. 68.—General Electric Co. oil circuit breaker type "FK12."

The contacts for these breakers are usually made with flared copper fingers supported by heavy steel springs. The movable contacts had wedge-shaped copper blades slotted at the apex in such a way that oil is forced through the slots into the arc. Modifications of this breaker with independent poles placed in masonry compartments were used for large capacities and high voltages.

Modern Types.—The more modern types of FK-12 breakers are built in capacities of 300, 500, and 800 amperes with a single blade contact, while the FK-12B is made with a single blade for 1000 amperes and with double blades for 1200 and 1500 amperes, the latter arrangement being shown in Fig. 68.

The frame is a single metal casting, supporting all of the breaker parts. Suspended from it is the oil tank of heavy sheet metal with welded joints. The oil tanks of single-pole breakers are lined with fibre and those of the multipole breakers with treated laminated wood. Multipole breakers have barriers of the same special wood between poles.

The operating mechanism, carried on the frame, is designed to produce parallel movement of the blades with the breaker opening by gravity assisted by the springs on the contact fingers and on the mechanism. The operating rods attached to the mechanism are made of specially treated wood, screwed and clamped into the crosshead and into the movable contact blade. This blade is wedge-shaped, confining the arc to the top of the blade and protecting the actual contact surface from the damaging effect of the arc.

The fixed contacts are drop-forged copper fingers secured to the blocks at the lower end of the terminal studs. The fingers are flared at the tips and one set is extended to act as arcing tips. These contact studs and clip blocks are of one-piece solid drop-forged copper, placed in bushings of one-piece glazed porcelain extending below the level of the oil. The bushing clamps are interchangeable metal plates with trued surfaces which firmly secure the insulator to the frame in proper alignment.

Ratings.—The rupturing capacities assigned to the FK-12 and FK-12-B breakers built for various voltages are 700 amperes. at 22,000 volts, 1200 at 15,000, 2760 at 7500, 4840 at 4500, 9000 at 2500 and 30,000 amperes at 750 volts.

Type K-32.—These FK-12 and FK-12-B breakers are being superseded by the FK-32-A and FK-32-B standard unit designs that can be assembled as single, double, triple, or four-pole combinations. Fig. 69 shows a 15,000 volt, 800 ampere, FK-32-*B* breaker with tank lifter and one of the tanks dropped to show the type of contacts used.

The fixed contacts for the FK-32-A breakers of 400 and 600 amperes are of wedge construction, double break per pole and make sliding contacts under heavy pressure when the breaker is closed.

The fixed contacts for the 800 and 1200 ampere FK-32-A breakers and all FK-32-B breakers are of laminated brush construction and double break per pole. Wiping motion at closing insures clean surfaces on the wedge or brush contacts. With all sizes, the arc is broken on secondary renewable contacts of copper, which close and open after the main contacts. The operating mechanism is simple and positive in action, with the breaker opening by gravity and compression springs. The frame supports the breaker mechanism and the standard breaker units, each with its own tank.

The tanks are approximately elliptical in cross-section, of heavy sheet steel lined with treated pressboard to protect the tank against the action of the arc. Strong supporting rods hook at the bottom of the tank and, extending through the cover above, hold the tank firmly.

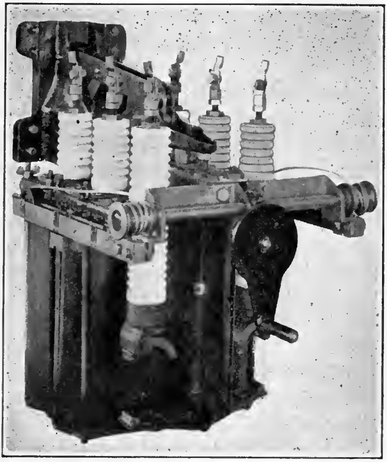


Fig. 69.—General Electric Co. oil circuit breaker, type FK-32.

Ratings.—The rupturing capacities assigned to the FK-32-A breakers are 1900 amperes, at 15,000 volts, 4370 at 7500, 7670 at 4500, 14,300 at 2500, while for the FK-32-B they are 2900 at 15,000, 6670 at 7500, 11700 at 4500, 21,800 at 2500 volts.

Type K-35.—The FK-35-Y and FK-35 breakers are also built on the standard unit construction, and are intended for lower voltages and lower currents than the FK-32-A and FK-32-B. The rupturing capacities assigned to the FK-35 are 2100 at 7500, 3900 at 4500, 7550 at 2500 and 20,000 at 750 volts.

The types FK-32A and FK-32B oil circuit breakers can be furnished for manual operation mounted on panel, panel frame, or remote on framework and for solenoid operation mounted on framework or in cell.

Cell Type.—For masonry compartment mounting, the FK-52B breaker as shown in Fig. 70 is built for 15,000-volt service for mounting on four-foot centers and for 25,000-volt service on six-foot centers. Each unit is supported on steel bedplates in a separate cell compartment and is leveled and bolted to these plates. The operating rod of each pole passes up through the top of the cell and a hand or solenoid mechanism can be furnished for operating all of the poles at the same time.

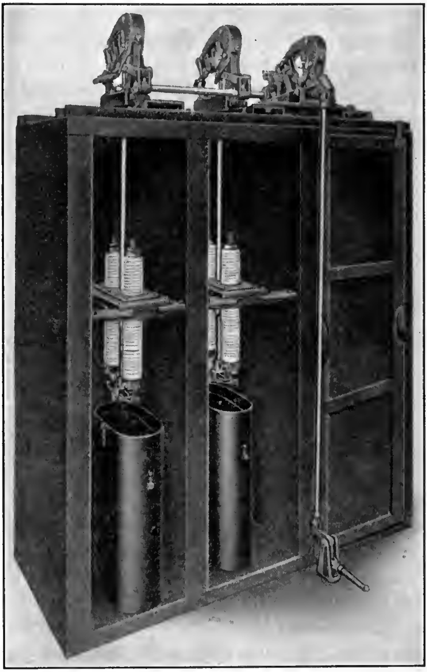


Fig. 70.—General Electric Co. oil circuit breaker type K-52B.

The operating mechanism is designed to produce parallel movement of blades. It has rustproof parts and noncorrosive pins. The breaker opens by gravity assisted by springs on the mechanism. An oil dash is used to buffer the mechanism at the end of the opening stroke and balancing springs help to carry the weight of the moving parts in closing. Provision is made for the insertion of a removable lever for emergency operation.

The tanks are approximately elliptical in cross-section and are made from heavy sheet steel, acetylene welded, and lined with pressboard. They are supported from the cover by bolts, which hook under the bottom of the tank and pass through the cover where they are securely fastened. Oil gauges and gas vents are provided for all tanks.

The bushings for 15,000 volts are of one-piece wet-process porcelain extending below the level of the oil. For 25,000 volts a short extension is clamped to the main insulator, thus giving the contacts a greater depth in the oil.

The main contacts are of laminated brush construction making end contact with heavy and uniform pressure, without any tendency to force any laminations of the brush apart. Wiping motion at closing keeps the contacts clean.

Up to and including 1200-ampere capacity, round studs are screwed and sweated into the brush block; 1600-and 2000-ampere capacities have laminated studs.

Ratings.—The 25,000 volt FK-52-B have rupturing capacities of 3450 amperes at 25,000, 6400 at 15,000 while the 15,000-volt FK-52-B have rupturing capacities of 5800 at 15,000, 13,350 at 7500, 23,500 at 4500, 43,500 at 2500 volts.

Type H.—The 'H' line of breakers covers the high rupturing capacity types used principally in stations distributing at the generator voltage and handling large amounts of power. These breakers have one tank per lead, six for a 3-pole breaker, the tanks being cylindrical and normally located in masonry compartments. The H-1 breaker was the original pneumatically operated breaker, the H-2 was the electro-pneumatically operated, the H-3 was and still is the motor operated breaker with pots 8 inches in diameter, the H-4 was the high voltage design of 'H' construction using wooden pots, the H-5 was a hand operated breaker. The H-6 was, and is the motor operated with 10-inch diameter pots, and the H-9 is the motor operated breaker with 12-inch diameter pots.

Old Type H3.—Fig. 71 shows one of the oil breakers supplied to the generating stations and substations of the New York Central & Hudson River R. R. With this type the leads are brought to the bottom of the two metal tanks in each compartment, and the circuit is completed through the plunger rods that pass through insulated bushings in the top of the tanks. These rods are connected together by metal crosspieces, and where the amount of current exceeds that which the plunger rods can carry, laminated copper brushes are used for bridging across between the pots. The brushes and plungers are lifted by means of wooden rods, operated by a motor driven mechanism located at the top of the breaker. Each pole of the breaker is installed in separate masonry compartments, and fireproof doors are used for closing

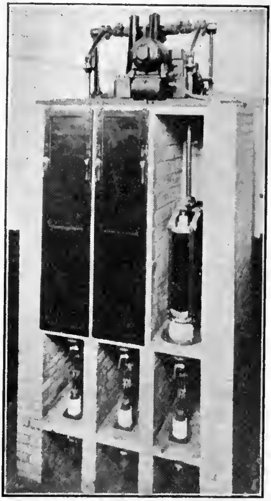


FIG. 71.—General Electric Co. oil circuit breaker type H3.

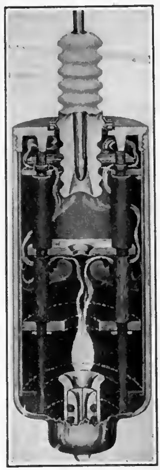


FIG. 72.

in the compartments. This style of breaker is very compact and is particularly well suited for connecting to busbars, located directly below the breaker on a lower gallery.

For larger currents, where the plunger contacts cannot readily take care of the amount of current to be handled, auxiliary conducting bars are run outside of the pots from the bottom contact, attached to insulator, to the top, where plates are placed on the tanks and brushes span across between the two tanks of the same phase.

Tank Section.—Fig. 72 shows a sectional view through a tank of an H-3 breaker in the open position with the plunger rod withdrawn to the extreme limit of the stroke. In the closed position the tip of the plunger rod engages with the stationary contacts at the extreme bottom of the tank and has a fairly long bearing surface to secure self-cleaning action between the moving rod and the stationary contacts. A baffle plate is provided about half way through the oil and about 40 per cent. of the space in the top of the tank is left available as an air compression chamber to take up the shock of the explosion when opening under load.

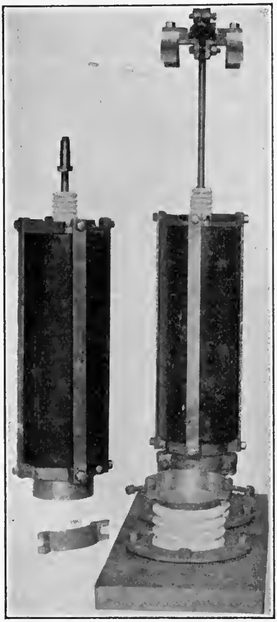


FIG. 73.

The cut represents what is supposed to happen in the tank at the instant of opening under load. The arc has a tendency to follow after the moving contact and a gas bubble is formed that is largely prevented from following after the moving contact by the action of the baffle plate. This minimizes the disturbance of the oil in the upper part of the tank.

By the adoption of the demountable type of tank construction shown in Fig. 73 the time needed for taking down a tank is reduced to a minimum and by keeping a few spare poles available a new one can be quickly substituted and the replaced one examined when a suitable opportunity arrived.

This same feature has been embodied in the H-6 and H-9 types of breakers to gain the same advantages.

Type H-6.—To secure greater rupturing capacities than could be obtained in the 8-inch pots of the H-3 breakers, the H-6 line of breakers was brought out with 10-inch diameter pots and these in turn have been followed by the H-9 line of breakers with 12-

inch pots. Still larger pots can be supplied if necessary, or two or more pots used in series to obtain greater rupturing capacity.

Fig. 74 shows a type H-6 breaker, 1200 amperes, 15,000 volts, with the parallel arrangement of tanks. This is the manner in

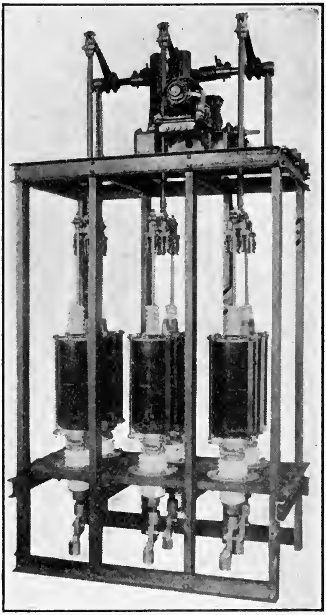


Fig. 74.—General Electric Co. oil circuit breaker type H6 with parallel pots.

which the breaker is normally arranged, but for certain conditions such as for bus sectionalizing circuits, the tandem arrangement of pots as show in Fig. 75 works out to advantage.

These breakers are usually made bottom connected but the parallel pot breakers can easily be arranged with the rear tanks top connected. With the tandem pots, all can be made top connected if this best works into the scheme of wiring.

With the H-9 breakers in a recent installation the position of the pots was a compromise between the parallel pot and the tandem and might be described as the staggered pot arrangement. The pots were all top connected and the front pots were sufficiently to one side of the rear pots that the leads could be run straight back without any interference. Other modifications of the 'H' line of breakers can be made to meet local conditions.

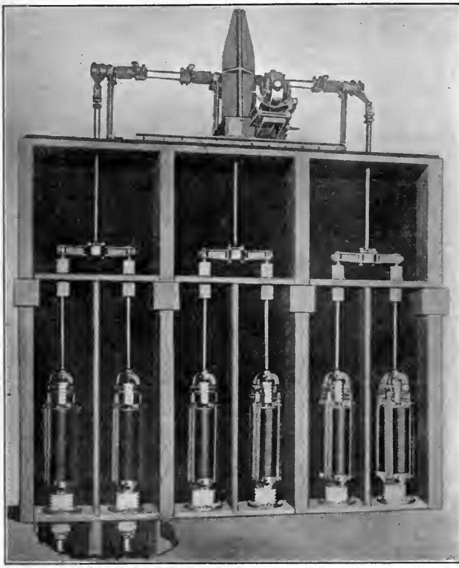


FIG. 75.—General Electric Co. oil circuit breaker type H6 with tandem pots.

Mechanisms.—The mechanisms for the types FH-3 and FH-6 oil circuit breakers have the following features:

Speed.—The contacts part in 0.2 seconds after contacts of overload relay or control switch close, and the switch is completely opened in 0.59 seconds. A complete cycle, opening and closing can be accomplished in 2 seconds. Torsion springs counterbalance the weight of the mechanism, making equally rapid motion for either stroke.

Compression springs throw the breaker about 1 inch into contact on closing and about 1½ inches from full stroke on opening, both with a rapid movement. The stroke is completed by the motor. The motor completes the stroke begun by the compression springs and compresses the operating springs at the end of each stroke (either opening or closing), thereby preparing the breaker for the reverse operation.

The master finger closes a circuit paralleling the safety switch at the first movement of the switch mechanism, thereby insuring the completion of the operation.

The magnetic clutch disconnects the motor from the mechanism when not needed, preventing injury to the motor by sudden stopping of the mechanism.

Ratings.—The rupturing capacity assigned to these breakers is as follows:

Volts	2,500	4,500	7,500	15,000
H-3 Amperes.....	75,000	40,300	23,000	10,000
H-6 Amperes.....	135,000	72,600	41,400	18,000
H-9 Amperes.....	150,000	92,700	52,900	23,000

For the smaller current ratings at the lower voltages the ratings are limited to 100 times the normal ratings of the breakers as the carrying capacities of the contacts are the limiting features.

High Voltage Breakers.—All of the high voltage breakers of the General Electric Company now in standard production are of the 'K' lines with various sub-number designations, the numerals such as 24, 26, 36, etc., being followed by the letter 'O' where the breakers are used for outdoor service. These breakers are built for pipe frame mounting up to 50,000 volts, for structural frame mounting for 73,000 volts and for platform mounting for higher voltages.

Type FK-24.—Fig. 76 shows a 15,000-volt 500-ampere FK-24 breaker for indoor service. Each pole is in a separate steel tank, the individual tanks being on a common frame and operated by a common mechanism that is designed to produce parallel movement of the blades. This mechanism has rust proof parts and noncorrosive pins. Provision is made in the mechanism for insertion of a removable hand-closing lever. Where space is limited, the breaker can be furnished with a one-piece top, supporting all of the elements.

Hung from the top are the tanks of heavy sheet steel, acetylene welded, with separate tank for each pole, and oil gauges for each tank. The bushings are one-piece porcelain made by the wet process and extending below the level of the oil. These bushings are held in clamps with interchangeable metal plates with trued surfaces to get proper alignment and to facilitate removal and inspection.

The fixed contacts are made of forged copper fingers at the end of the terminal studs that pass through the bushings. The fingers are flared at the tips and one set is extended to act as

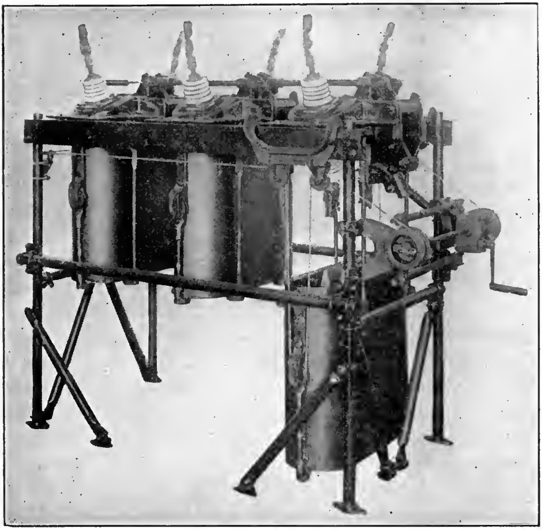


FIG. 76.—General Electric Co. oil circuit breaker type FK24.

arcing tips. The movable contact blade is screwed and clamped to the operating rod. The contacts are wedge-shaped which confines the arc to their top edge and to the flared portion of the finger tips.

Ratings.—The rupturing capacities of the 35,000-volt FK-24 breaker is 1100 amperes at 35,000 volts; 1670 at 25,000; for the 25,000-volt breaker 1500 at 25,000; 2800 at 15,000 and for the 15,000-volt breaker 2500 at 15,000, 5750 at 7500.

Type FK-26.—Fig. 77 shows a frame mounted FK-26 breaker for indoor service at 45,000 volts. Most of its features correspond with those of the FK-24 previously described, but the general dimensions are considerably larger and the bushings instead of being of the porcelain type are of built up material with a contact tube extending through it and binding together the upper and lower sections. A maple cover keeps out dirt and protects the end of the bushing. Porcelain ends prevent injury to the bushing by any arc or discharge that might occur.

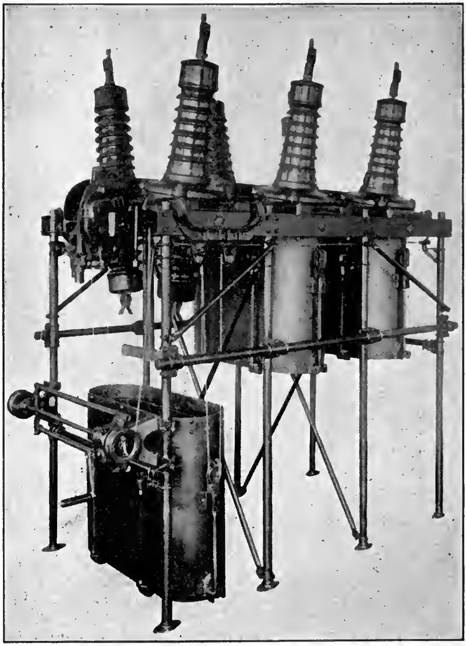


Fig. 77.—General Electric Co. oil circuit breaker type K26.

The interior of the 45,000-volt bushing has the contact tube surrounded by an insulating material and the bushing filled with an insulating compound of high dielectric strength. The bushing for 70,000-volt service has a set of cylinders of insulating material concentric with the contact tube, the whole being filled with an insulating compound. At the bottom of the 70,000-

volt bushing that is under the oil a static shield is provided that partly surrounds the contacts.

Type FKO-26.—Fig. 78 shows the FKO-26 breaker for frame mounting outdoor service, this differing principally from the indoor type in the waterproof covering for the operating mechanism and the porcelain rain shields over the portions of the bushings that are exposed to the weather. With all of these breakers,

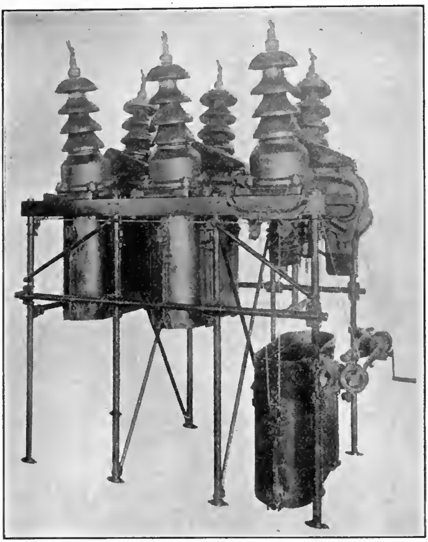


Fig. 78.—General Electric Co. oil circuit breaker type KO26.

the cast-iron support built into the bushing serves as the means of attaching it to the breaker. Where bushing transformers are used, this cast-iron housing is made large enough to house and protect them.

These breakers can be supplied for floor mounting or for frame mounting. The framework for the 50,000-volt breaker is made of pipe while that for the 73,000 is made principally of channel irons.

The rupturing capacities for the 70,000-volt breakers are 1950 amperes at 70,000 volts; 2200 at 50,000; 2500 at 45,000; 3130 at

37,000 and for the 45,000, 1600 at 45,000; 2050 at 37,000 and 3260 at 25,000.

Type FKO-36.—Fig. 79 shows a floor mounting FKO-36 for outdoor service, this breaker having a guaranteed rupturing

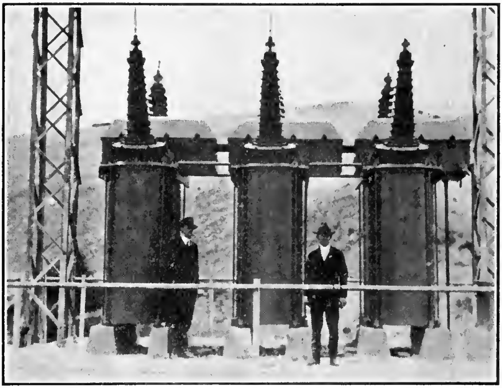


Fig. 79.—General Electric Co. oil circuit breaker type KO36.

capacity of 3290 amperes at 110,000 volts. The sides of this tank are practically flat but the arc is broken under the oil in a special explosion chamber shown in Fig. 80.

Fig. 80.—General Electric Co. oil circuit breaker type KO36. Explosion chamber.

The function of this explosion chamber is based on the theory that by confining the arc to a largely restricted space a high pressure will be developed tending to blow the arc away from the contact causing its rapid extinction. The steel cylinder forming the explosion chamber can be readily made of ample strength for the pressure developed.

Ratings.—The FK-36 and FKO-36 are built with various sized tanks and given varying rupturing capacity ratings. For example at 155 K.V. breakers are available with rupturing capacity ratings of 900, 2300 and 3500 amperes; for 135 K.V. the ratings are from 950 to 3600 amperes; for 115 K.V. from 1000 to 4400 amperes, etc.

Modifications of these breakers are available and in services up to 160,000 volts and designs have been made for service at 220,000 volts and such breakers are now being built for California.

WESTINGHOUSE OIL CIRCUIT BREAKERS

While the Westinghouse Company had made oil switches and oil circuit breakers in various forms prior to 1904, their annual catalogue of that year was their first one with various lines of oil circuit breakers and switches listed and described in it. At that time the term *oil switch* was applied to those pieces of apparatus in which the contacts were of the knife type that did not have any tendency to come open and the term *oil circuit breaker* was applied to those pieces of apparatus so designed that the contacts tend to separate and were only held in the closed position by means of triggers and toggles.

In the descriptions that follow, the oil circuit breakers are taken up about in the order of their rupturing capacity in place of alphabetically by type letters.

Knife Contacts.—Type I oil circuit breakers, manually operated, non-automatic, for indoor service, single and double throw, are made for capacities up to 60 amperes 4500, volts A.C., interrupting capacity at rated voltage, 300 amperes. The characteristic features of the type I oil circuit breakers are: knife blade contacts submerged in oil; live parts carried on porcelain base affording high quality of permanent insulation between adjacent poles, and between frame and live parts; small space required for mounting; light weight; tanks removable without disturbing contacts, making easy accessibility of parts for purpose of inspection and repairs; enclosure of all live parts; and low first cost. The breaker is essentially a knife switch submerged in oil and arranged for external operation.

Type D.—Type D oil circuit breakers are manually operated non-automatic made for indoor, outdoor and subway service, single and double throw, for capacities up to 300 amperes, 1500 volts, 200 amperes, 4500 volts, alternating current, interrupting capacities at rated voltage 700 to 800 amperes.

These non-automatic oil circuit breakers have a wide range of application, being made for indoor service in panel mounting, direct wall-mounting, remote-control wall or pipe mounting, and for subway mounting.

Outdoor Type.—The outdoor form of wall or pole mounting breaker is primarily intended for service in exposed places.

The wall or pole mounting breaker is enclosed in a weatherproof case having lugs cast thereon for mounting the breaker on a wall or pole. On these outdoor breakers a crank handle is used for operation. The leads are brought out underneath the top part of the case, through sealed bushings at the side and underneath the main casting. The sealing-in of the bushings prevents the entrance of rain or moisture to the interior of the breaker.

Subway.—The subway form of breaker is intended for mounting in subways, manholes, or other places where a breaker may be required to operate submerged. This subway form of breaker is made in 2, 3 or 4-pole, single and double throw, for capacities up to 200 amperes, 4500 volts.

The housing for the subway breaker complete, including the oil tank, is of cast iron. All housing joints are made waterproof by the use of gaskets. The housing has lugs cast thereon for mounting the breaker on the wall of the subway, manhole or other place of mounting.

The leads enter the breaker housing through individual waterproof bushings in the top of the case. The operating handle is provided with a waterproof stuffing box and is latched in either the "on" or "off" position.

Features.—The characteristic features of the type D oil circuit breakers are: knife blade contacts submerged in oil and protected by auxiliary arcing contacts; live parts carried on insulating supports affording a high quality of permanent insulation between adjacent poles, and between the frame and live parts; all parts supported by a single frame easily mounted on panel, wall, pipe frame, post, bracket, or other vertical support; small space required for mounting; accessibility of parts for the purpose of inspection and repair; enclosure of all live metal parts; simple but rugged construction.

Tanks.—The oil tanks are rectangular in shape and are made of heavy sheet iron. Individual insulating cells on single-throw breakers, and an insulating lining on double-throw breakers, are used as an additional protection against arcing from current-carrying parts to the metal of the tank. Where the individual insulating cells are used on the single-throw breakers, they form a separate compartment for each pole. While the tank is securely fastened to the breaker frame, the construction permits of easy removal for the purpose of inspection and repair.

The tanks are deep to allow ample space above the oil level to act as an expansion chamber for the arc gases, and to reduce slopping of the oil from internal disturbances. The gases are vented through the clearance between the wooden operating rod and the frame.

Type F.—Type F oil circuit breakers are made manually and electrically operated, non-automatic and automatic, for indoor and outdoor service, single and double throw, for capacities up to 3000 amperes, 13,200 volts A.C., interrupting capacities at rated voltage, 1000 to 15,000 amperes.

These type F oil circuit breakers comprise a complete line of moderate-capacity, non-automatic and automatic, manually and electrically operated breakers. For indoor service, the breakers are made in the panel mounting, and remote-control wall or pipe mounting forms, and for outdoor service in pole or subway mounting forms.

Among the features of the type F breakers are: Wedge and finger-type contacts. Auxiliary arcing contacts. Submersion and opening of all contacts under oil. Quick opening of contacts, assisted by arcing tip springs. Open position maintained by gravity. Inability to hold full automatic breaker in the closed position when an excessive overload or short circuit exists on the line. Strong tanks and tank supports. Tanks removable without disturbing the operating mechanism or contacts, making inspection easy. Ample air space at the top of the tank to allow for gas expansion. Insulating lining in the tanks. Isolation of poles by individual cells. Self contained multipole hand- or electric-operating mechanism on the multipole single-tank breakers.

The type F oil circuit breakers are made non-automatic and full-automatic, direct or remote-control manually operated; and non-automatic and automatic electrically operated.

Type F-1.—Fig. 81, shows a type F-1 indoor manually operated remote-control pipe mounting three-pole single-throw 200-ampere, 4500-volt breaker with micarta tubes over terminals and with tank removed. The standard overload-trip range of these breakers is 80 to 160 per cent. of the normal full-load current rating or primary rating of the current transformer in the trip coil circuit.

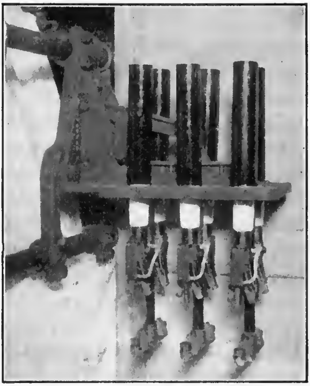


FIG. 81.—Westinghouse oil circuit breaker, type F-1.

Transformer Trip.—For this method, type F automatic breakers are made with trip coils mounted on the coverplate of hand operated breakers or on the electric mechanism of electrically operated breakers. A single 5-ampere coil is regularly used on single pole and 2-pole breakers, and two 5-ampere coils on 3-pole and 4-pole breakers. For use on 2-phase or 3-phase, where accurate overload tripping is not required on a single-phase overload or short circuit, single coil 3- and 4-pole breakers having only one special 8.7-ampere overload trip coil, are obtainable. This special trip coil can be connected to two current transformers in "vector parallel," in which case the single-phase overload accuracy is within good operating limits of the polyphase calibration.

Series Trip.—For series tripping, type F indoor breakers are made with alternating-current series-overload trip coils mounted in the switchboard cover plate dry insulated, for voltages up to 2500 and capacities from 10 to 300 amperes.

Multiple-Multipole.—Multipole breakers having a single mechanism and tank are made up to maximum capacities of 800 amperes. In addition, type F-3 breakers, either manually or electrically operated remote control, can be supplied in capacities up to 3000 amperes by using 3 or 4-pole standard units with the contacts connected in multiple for each pole, (multiple-multipole). Type F-3 breaker frames are specially designed for this purpose.

Manual Operation.—Manually operated direct control breakers are made either for panel or panel-frame mounting, or for remote control wall or pipe mounting. The type F-2 multiple single-pole wall mounting breakers (a multipole breaker made up of single pole units) and the type F-3 multiple-multipole wall mounting breakers (a multipole breaker made up of standard remote control 3 or 4-pole units to form one high capacity multipole breaker) when equipped with appropriate fittings, can be used for cell mounting, erected in brick, asbestos lumber, or concrete structure, with each pole enclosed in a separate compartment.

Electrical Operation.—Electrically operated multipole single-tank breakers are made with self-contained mechanisms for either wall or pipe mounting. The multiple single-pole electrically operated breakers are made for either wall or pipe mounting with separate operating mechanisms placed above, below, or behind the breaker, while the electric operating mechanism of the multiple-multipole breakers can be mounted only below the breaker.

Tanks.—Multipole single tank construction is used on all type 'F' breakers, except the type F-2 multiple single-pole, and the type F-3 multiple-multipole, which use one tank per pole. The oil tanks are rectangular in shape and are made of heavy sheet-iron with all seams lap-welded, the bottom being flanged and welded on the outside of the tank sides. As an additional protection from arcing, individual insulating cells form separate compartments for each pole where one tank is used on multipole breakers.

Studs.—The terminal studs or bushings with stationary contacts or feet on the lower extremity are supported by one-piece vertical pillar type porcelain bushings clamped to the framework. The studs and micarta-tube details are clamped to these insulators. This construction avoids the use of babbitt and cement, thus reducing the time and labor of maintenance.

Contacts.—The main moving contacts are wedge type. The main stationary contacts consist of fingers of the "controller" type arranged in pairs facing each other so as to make perfect contact on the two surfaces of the moving contact wedge when the breaker is closed. The contact tips on the end of the fingers are supported on the ends of thin flat steel springs, permitting the contact to move in all directions and to automatically align itself on the wedge, thus insuring that the full carrying capacity of the contacts is always available. This spring is shunted by a liberal copper-leaf shunt to conduct the current from the tips to the terminal stud.

Arcing Contacts.—These are made of the butt type to protect the main contacts from the action of arcs at breaking. The stationary member consists of a spring plunger and copper arcing tip mounted on the support of the main contact. A flexible copper wire shunt carries the current from the stud to this tip. A copper bolt is carried on the conducting cross-bar of the moving contact element and serves as the moving arcing contact. The auxiliary arcing contacts maintain contact for a considerable distance after the main contact fingers have broken contact. This time interval is predetermined by the amount of separation of the main contact fingers produced by the steel stop and serves to fully protect the main contacts.

Type H.—These oil circuit breakers are small capacity manually operated single-throw breakers for indoor use (dust-proof wall mounting) and outdoor use (weatherproof, wall or pole mounting). These breakers supply the need for a simple, reliable, inexpensive oil circuit breaker for use in general industrial applications. They are particularly useful for controlling motor circuits, or other loads of low power factor, where excessive arcing would occur when using an air-break switch at low power factor, thus making the use of an oil circuit breaker advisable. The cylindrical-rod butt-type contact is used. The contacts consist of cylindrical rods, the lower one backed by spiral springs to insure contact. This type of contact is used on the multiple unit control system of heavy street-railway equipment and has been adapted with great success to oil circuit breaker practices. It insures good contact at all times, and prevents any possible failure due to the eating away of the contact by continued arcing. The compression springs take up any wear that may occur. The contacts have long life, and are readily removed and replaced when necessary.

Type QF.—The type 'QF' motor starting oil circuit breakers shown in Fig. 82, are especially designed for starting, in connection with auto transformers, 3 phase squirrel-cage induction and self-starting synchronous motors up to 720 H.P. When properly applied they protect the motor in the running position from heavy overloads and short circuits, and guard it against the sudden application of full voltage to the motor after it has slowed down or come to rest following an interruption of power.

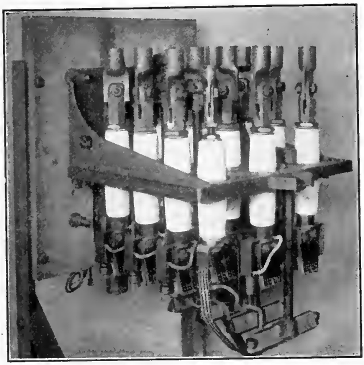


Fig. 82.—Westinghouse type "QF" Motor starting oil circuit breaker.

The type QF motor starting oil circuit breaker is a double-throw breaker with special moving and stationary contact arrangement. In effect, it is a 3-pole, double-throw breaker with three additional terminals used to complete the auto-transformer circuits when the breaker is in a starting position. The auto transformers are mounted separately from the breakers. The tap leads of the transformers are permanently connected to the motor leads.

Type B.—The modern type 'B' oil circuit breakers comprise a line of medium capacity breakers built of three different forms, namely, types 'BA,' 'B-2,' and 'B-13,' each with a different interrupting capacity, different maximum voltage and details of construction.

These breakers have a wiping and self-cleaning form of laminated brush contact, protected by butt arcing contacts. The opening of all contacts occurs under oil with a positive direct gravity break assisted by spring acceleration, and with open position maintained by gravity. The type 'B' circuit breaker is in general a common-frame circuit breaker. The type 'B-A' has a tank per pole in all sizes. The type 'B-2' has a tank per pole in the 300-ampere and 600-ampere sizes, but a single tank construction in the other sizes. The type 'B-13' has a tank per pole in all sizes.

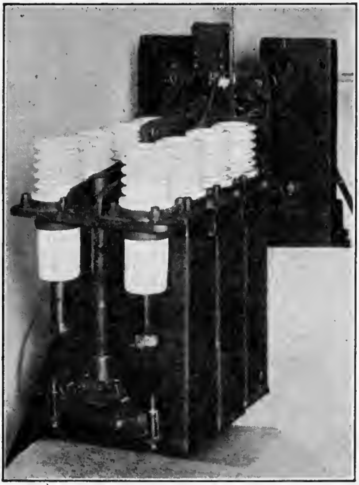


Fig. 83.—Westinghouse type "BA" oil circuit breaker, 300 amps., 15 K.V.

Manually operated circuit breakers are actuated by a handle mounted in the switchboard cover plate. When the breakers are supplied with automatic overload trip with remote control, an accelerating spring device is used to quicken the opening of the contacts, and this device, assisted by the arcing contact springs, gives to the moving parts an acceleration greater than that caused by gravity.

Fig. 83 shows a 4-pole 300-ampere, 15,000 volt 'BA' oil circuit breaker with one tank removed, showing contact details on one pole. Fig. 84 shows a 3-pole-solenoid operated

'B-13' breaker 600 amperes 25,000 volts arranged for pipe frame mounting. All of the following sizes of circuit breakers can be supplied either manually or electrically operated and either automatic with transformer trip coils or non-automatic. The manu-

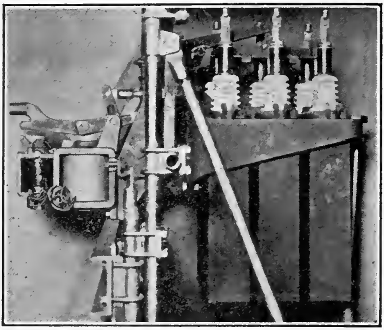


FIG. 84.—Westinghouse oil circuit breaker type B13.

ally operated breakers can be panel or panel frame mounting or remote control, while the remote-control breakers, both hand and electrically operated, can be furnished for wall mounting or pipe frame mounting. All can be furnished in 2, 3 or 4-pole types.

Type	Maximum Amperes		Maximum volts	Interrupting capacity in arc amperes at rated voltage
	60 cycle	25 cycle		
BA	300	400	15,000	1,350
BA	600	750	7,500	3,500
B-2	300	400	15,000	1,900
B-2	300	400	25,000	960
B-2	600	750	15,000	1,900
B-2	600	750	25,000	960
B-2	1,200	1,350	15,000	1,900
B-2	1,500	1,750	7,500	3,000
B-2	1,750	2,000	7,500	3,000
B-2	2,000	2,250	7,500	3,000
B-13	300	400	25,000	1,630
B-13	600	750	25,000	1,630
B-13	1,200	1,350	15,000	3,400

Multiple-Multipole.—These type B oil circuit breakers can be furnished for applications requiring a breaker having current carrying capacities up to 6000 amperes, 60 cycles. As indicated by their name, these breakers consist of a number of multipole single frame breaker units, each unit having its poles connected in multiple to serve as one phase leg. All phase leg units are operated simultaneously by means of a common operating shaft and bell cranks. For example, a 4800-ampere 3-pole type B-2 multiple-multipole breaker consists of three 2000-ampere, 3-pole units. The poles of each 3-pole unit are connected in parallel, thereby forming one 4800-ampere pole. Three such poles units operated simultaneously meet all the requirements of a 4800-ampere 3-pole breaker.

Connections.—In making connections to a multiple -multipole breaker care must be exercised not to "bus" the connections at the breaker studs on both sides. If this is done the contact resistance of the connections is the only source of voltage drop. Thus a slight increase in contact resistance on one stud of a **"bussed"** connection results in the other studs in the same parallel circuit taking more than their share of the current, heating develops and then the results are cumulative. Any difficulties from such a source can be overcome by using cables to connect to the breaker on at least one side. The number of cables should be the same as the number of parallel circuits through the breaker or multiples thereof. The resistance of the relatively long cable connections is such that even a 100 per cent. change in the contact resistance at one stud would be but a small percentage change in the total resistance of the total parallel circuit and no uneven distribution of the current results.

Mounting.—The type B breakers are arranged for either panel, panel frame or pipe frame mounting direct-control; and in the remote-control form, for wall or pipe frame mounting. The remote-control breakers can be mounted in cells, the single frame circuit breakers being mounted as a unit in one cell, which can be made of brick, asbestos lumber, or concrete.

Tanks.—These are rectangular in shape except on the 1200 ampere and 2000-ampere type B-13 breakers which have elliptical tanks similar to those supplied on the type E line of breakers. The tanks are made of heavy sheet-iron, with all seams lap-welded, the bottom being flanged and welded on the outside of the tank sides. The tanks have a micarta lining, and where one tank is used on multipole circuit breakers, individual insulating cells form separate compartments per pole.

The tanks are especially deep to give a large head of oil over the contacts, to allow ample space above the oil level to act as an expansion chamber for the arc gases, and to reduce spilling of the oil from the internal disturbances. On the type B-A and B-2 circuit breakers, the gases are vented around the lifting rod. The type B-13 circuit breakers are equipped with specially designed baffled vents.

Moving Contacts.—The main moving contacts are of the laminated butt brush type. When the high contact pressure used is imposed on the movable contact (the butt brush), its contact surface spreads out on the stationary contact (a plane surface) producing a wiping action which automatically cleans both the stationary and moving contact faces.

Stationary Contacts.—The stationary contacts are mounted on the lower end of the terminal studs and provide a liberal contact surface. The moving contacts of each pole of the breaker are connected to the mechanism by an insulating rod. The contact pressure is obtained by adjustable features which equalize the pressure on both ends of the moving contact element.

Arcing Tips.—The main contacts are protected from burning when opening heavy overloads or short circuits by the use of butt-type arcing tips. The moving member consists of a plunger actuated by a spring mounted on the support of the moving main contact brush. A copper arcing tip is bolted on the main stationary contact in such a position that the head makes contact with a similar tip on the arcing plunger. These arcing tips are easily and inexpensively renewed when burned. A flexible copper strap shunt carries the current between movable plungers.

The arcing contacts maintain contact for a considerable distance after the main contacts open; and, being placed outside the main contacts, the arc formed between them is automatically blown away from the main contacts, the auxiliary contacts thus taking all the arc.

Type E.—These oil circuit breakers were originally built for hand operation only and designed for mounting in a masonry compartment. In 1904 they were listed up to 100 amperes at 25,000 volts, 300 amperes at 16,500 volts, 600 amperes at 7500 and 1200 amperes at 3500. Their rating converted to the modern methods of figuring would be expressed in amperes corresponding to about 65,000 K.V.A. at the various voltages mentioned.

Old Forms.—The smaller frame breakers that had been utilized in the 300 and 600-ampere sizes for cell mounting became the E-1 breakers for cell mounting; the larger breakers for cell mounting became the E-2 and the corresponding frame mounted breakers became the E-3 and E-4, these being suitable for mounting against a flat wall or on structural iron framing.

To facilitate erection, dismantling and repairs or inspection, the design of the E-2 was modified so that each pole could easily be slid into a steel channel set in the barrier walls between poles. The resulting design with a soapstone top was known as the E-5 and the pole width could be modified within certain limits by changing the size of the soapstone base.

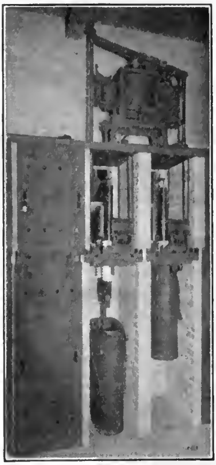


Fig. 85.—Westinghouse type "E-6" oil circuit breaker, 300 amps., 25 K.V.

Later Types.—When a definite width became standard and the top was made of steel in place of soapstone, the E-6 came into being and the same switch for frame mounting became the E-7.

Where a breaker of the 'E' line was desired but a smaller rupturing capacity than that of the E-6 would suffice, a smaller breaker was developed for cell mounting known as the E-8, and for frame mounting known as the E-9. For the neutral circuits of generators and for single phase circuits fed from 3-phase 4-wire systems, single-pole solenoid breakers were developed, known as the E-10, an adaptation of the older "E" mechanism being used. Three-pole breaker design has the three poles on a common frame, although occasionally three independent solenoids are used.

Fig. 85 shows a type E-6 cell mounting, electrically operated breaker in the open position with one tank lowered and two double doors of the cell structure removed.

Fig. 86 shows a 2000-ampere 4500-volt E-8 breaker, single-pole unit with tank removed, showing the stationary and moving contacts

The type E oil circuit breakers are particularly adapted to the control of alternating-current circuits of capacity from 25,000 to 40,000 connected turbo-generator K.V.A. and voltages not over 25,000. They are designed for indoor mounting apart from the switchboard and for either manual or electrical control.

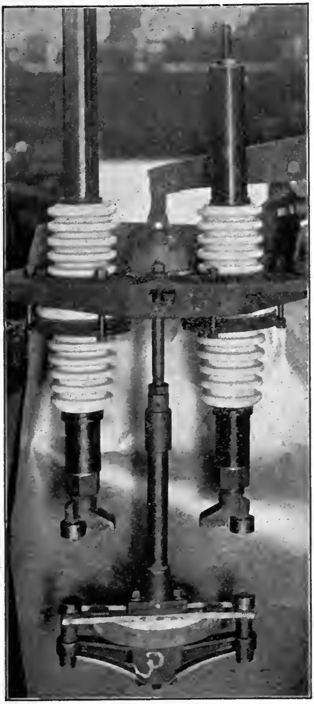


Fig. 86.—Westinghouse type E8 oil circuit breaker.

Features.—The following features particularly adapt the type E breakers to their class of service. Self-cleaning form of high-pressure laminated brush; main contacts protected by extra heavy arcing contacts; submersion and opening of all contacts under oil; quick opening of contacts, assisted by heavy accelerating spring; open position maintained by gravity; strong elliptical lap-welded steel tanks and steel tank supports; tanks removable without disturbing the operating mechanisms or contacts, making inspection easy; individual tanks enclose the contacts of each pole of the breaker; ample air space at top of tank to allow for proper gas expansion; insulating linings in tanks; unit-type electrical operating mechanism having closing, tripping, accelerating, and shock-absorbing features self contained; manually operated breakers tripped free of the mechanical remote control in the automatic overload-trip forms; inability to hold full-automatic overload-trip forms of breaker in the closed position when an excessive overload or short circuit exists on the line; each pole a complete unit, operated by independently adjustable connecting rods to the common electric or manual operating mechanism, and, in the cell mounting forms, installed in a separate masonry compartment.

Ratings.—The following sizes are built in either two, three, or four-pole breakers, manually or electrically operated.

Type	Maximum Amperes		Maximum volts	Interrupting capacity in arc amperes at rated voltage
	60 cycle	25 cycle		
E-6 and E-7..	300	400	25,000	5,350
E-6 and E-7..	600	750	25,000	5,350
E-6 and E-7..	1,200	1,350	25,000	5,350
E-6 and E-7..	1,600	1,800	15,000	10,000
E-6 and E-7..	2,000	2,250	15,000	10,000
E-8 and E-9..	600	400	25,000	2,200
E-8 and E-9..	600	750	25,000	2,200
E-8 and E-9..	1,200	1,350	15,000	4,500
E-8 and E-9..	1,600	1,800	7,500	10,300
E-8 and E-9..	2,000	2,250	4,500	18,200

Solenoid Control.—These breakers are operated by a solenoid mechanism that is mounted above the poles on the cell mounting breakers or on the floor for the wall, pipe frame or structural frame mounting breakers. The breaker is closed by a solenoid and is held closed by a hardened steel latch and a trigger which engage automatically. The closing solenoid is regularly furnished for use on 125-volt (normal) direct-current circuits and has a standard operating range from 70 to 140 volts. Coils for other than standard voltage with the same proportionate range can be furnished. Due to the wide operating range, breakers with the standard coil can be satisfactorily operated from 110-volt direct-current circuits.

Type E-6 and E-7 breakers have a device known as a "cut-off" switch supplied as an integral part of the electric operating mechanism. When properly connected and adjusted, it does not allow an automatic breaker being held closed on over load thus securing the trip-free feature.

Mounting.—These breakers are made for either cell or pipe mounting. The cell mounting breakers, types E-6 and E-8, are arranged for supporting the individual poles of the breaker in fire proof compartments of brick, asbestos lumber, or concrete structure with removable doors. The channel frame upon which the manually operated mechanism or electrically operated mechanism is mounted is placed on top of the cell structure. This construction provides, where necessary, for special wide spacing of the poles when reactance coils, two sets of disconnecting switches, etc., are used in connection with the breaker.

The pipe mounting breakers, types E-7 and E-9, are designed for mounting on horizontal pipe supports. All capacities of both types have the same dimensions of horizontally arranged pipe centers so that the installation of several different capacities can be made on a common pipe frame structure.

Unit Construction.—The type E breakers are made up of single-pole units, each having its own steel supporting frame and toggle arrangement for operating its moving contacts, so that all contact adjustments are made and locked before shipment. In the multipole breakers these individual pole mechanisms are in turn connected to a common operating mechanism controlled by the manually operated handle and trip coils or by the electric operating mechanism.

The individual toggle arrangement for each pole permits each complete pole to be placed in position and properly lined up. This arrangement also permits the adjustment of contact pressure and contact travel of each pole to be made independent of the other complete breaker poles.

On the cell mounting breakers the operating mechanism is mounted on a plate and channel frame structure fastened to the top of the cell structure. On the pipe mounting breakers the mechanism is mounted on the floor, to one side of the poles.

Latest Improvements.—Some of the latest improvements in the E-6 breakers are the tank cradle and tie rod method of supporting the tanks to obviate the possibility of the tanks being blown off by an explosion and the furnishing of reversed brushes on all breakers where the short-circuit current on the system might rise to such a point that the magnetic stresses would straighten out any ordinary brush of the usual wound copper strip construction. Instead of the brush in the form of a half ellipse being on the movable member, that member was made essentially straight and brushes in the form of a quarter of an ellipse were placed on the stationary contacts with the concave side down and turned in so that the magnetic force increased the pressure between the stationary and movable members instead of tending to diminish the pressure by straightening out the brush when it was mounted with the concave side downward. The new moving element is so stiff mechanically that the magnetic forces cannot distort its shape.

Type C.—The modern type C oil circuit-breakers are adapted to the control of circuits of large capacity, up to 60,000, connected turbo-generator K.V.A. and up to 15,000 volts. They are made for indoor cell mounting and for electrical operation only. They are especially used for lining up with existing installations of similar breakers, and are noted for their great compactness with high rupturing capacity.

The distinctive features of the type C breakers are the self-contained multipole operating mechanism with positive and direct solenoid operation, quick opening hastened by accelerating springs and open position maintained by gravity. The contacts open under oil, and are of a highly efficient form of brush with butt arcing tips. There is an expansion chamber with baffled vent for the arc gases. The poles are isolated in separate tanks and cells, the elliptical tanks being very strong, with exceptionally strong fastenings, and removable without disturbing any other part of the breaker.

Ratings.—The following sizes are built in three or four-pole units electrically operated with either vertical or horizontal arrangement of leads.

Type	Maximum Amperes		Maximum volts	Interrupting capacity in arc amperes at rated voltage
	60 cycle	25 cycle		
CG..........	600	750	15,000	14,000
CG..........	1,200	1,350	15,000	14,000
C-2..........	600	750	25,000	8,000
C-2..........	1,200	1,350	25,000	8,000
C-2..........	2,000	2,250	15,000	15,000
C-2..........	3,000	3,400	2,500	86,300

The breaker is designed for supporting the individual poles in fireproof compartments of brick or concrete structure with removable doors. Each pole of the breaker is covered by a cell door consisting of a metal frame with asbestos panels and hinged at the top to the iron mechanism base. The electric operating mechanism which controls all poles simultaneously is mounted on the cast-iron bedplate or base which covers the top of the cell structure.

FIG. 87.—Westinghouse type "C" circuit breaker installation.

Cells.—These breakers worked into very satisfactory structural arrangements, particularly in plants where the galleries could be so arranged that one row of breakers would be on a gallery below the busbars and the other one on a gallery above the bus. They also were well fitted for installations with the bus bar back of the breakers and particularly for a feeder and group arrangement, such as has been employed in many plants, that permit a generator to be readily used with either of two feeder groups immediately adjacent to it or to be connected to a main bus to facilitate parallel operations or tied on to a transfer bus to allow it to feed any set of feeder groups. Fig. 87 shows an installation of 'C' breakers arranged for group feeder operation with one row of breakers on an upper gallery with the generator bus back and above it, and a main bus back of the lower part of the breaker. On the floor below, the feeder breakers are arranged with the bus above them. There are two complete sets back to back arranged for a ring system.

Tanks.—In the type CG breaker, the tank construction is the same as that for the type G-1 oil circuit breaker, consisting of heavy sheet steel tanks, double lap-welded on the vertical seam, and having the bottom flanged outside and lap-welded.

In the type C-2 breaker, the tank construction is the same as that for the type "E" oil circuit breaker except that the top engages a flange on the expansion chamber instead of on the supporting frame as in the "E" breaker.

In the type CG breaker, the expansion chamber is supported from the ½-inch sheet steel bedplate by strong steel rods.

In the type C-2 breaker, wood strain insulators support the expansion chamber from the slate base portion of the bedplate, thus completely insulating the tank unit from ground.

In both types of breakers, the expansion chamber provides a large space above the oil level, into which the gases formed between contacts by the arc, at the time of opening the circuit, can expand. Each chamber has a vent to provide an exit for gases and these vents are baffled to prevent the throwing of oil when the breaker opens under heavy overloads or short circuits.

Mechanism.—The mechanism with operating coils is self contained on a single bedplate or base. To make the opening of the breaker rapid and positive, accelerating springs are used to force the breaker to the open position. Dashpots absorb the momentum of the mechanism in closing and in opening. The bedplate is also fitted with leather bumpers to support the weight of the moving contacts and rods after the dashpots have brought the breaker to rest in the open position.

Type O.—The modifications necessary for a 60-cycle breaker of about 4000-amperes capacity, involved the use of two sets of studs in parallel or a total of four studs per pole and this logically lead to a circular design of tank as special round tank E breakers and these worked out so well that a modified type of mechanism was developed and a line of breakers with 16-inch diameter round tanks became the type O-1, while corresponding breakers with 20-inch tanks became the type O-2.

With the type O-1 or O-2 breaker, as well as with the E-6, the unit type of construction is used and the pole units can be assembled as 2, 3 or 4-pole units with a single mechanism for operating all the poles simultaneously. Each pole is normally arranged to slide into a channel iron recess in the barriers between adjacent poles and the two channels set back to back

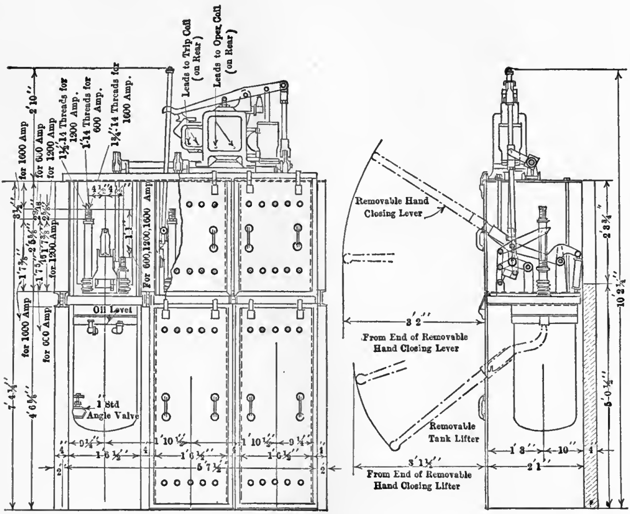


FIG. 88.—Westinghouse type "O-1" oil circuit breaker.

occupy the same thickness as a 4-inch barrier wall. This results in the minimum spacing between poles for normal construction. The substitution of an "I" beam for a double channel results in the saving of a centre distance of an inch, while the locating of the channels outside of the barrier walls means slightly greater spacing.

A typical 3-pole breaker type O-1 is shown in Fig. 88, this being the type of the breakers at the West Farms substation of the New York Edison Company controlling the supply of the single-phase electrification of the N. Y. N. H. & H. R. R.

Co. at that point. Fig. 89 is a 3000-ampere 3-pole type O-2 breaker.

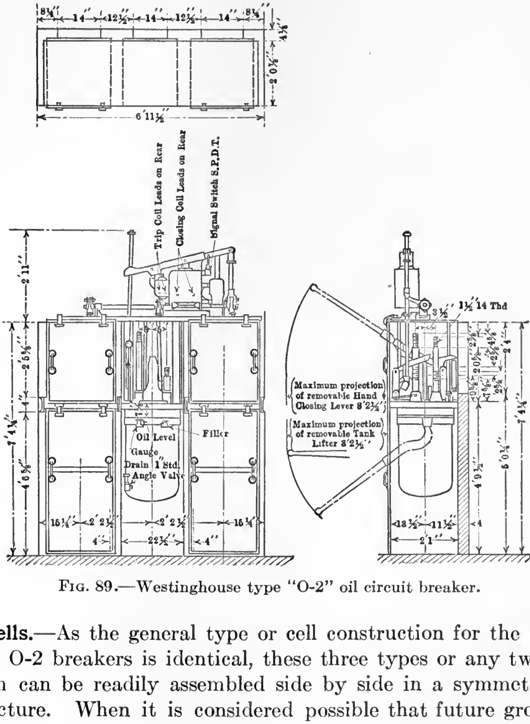


FIG. 89.—Westinghouse type "O-2" oil circuit breaker.

Cells.—As the general type or cell construction for the E-6, O-1, O-2 breakers is identical, these three types or any two of them can be readily assembled side by side in a symmetrical structure. When it is considered possible that future growth in a station may require larger breakers it is possible to put up structures for the O-2 breakers and slightly modify a type O-1 or E-6 breaker so that it can be arranged readily in the larger structure. O-1 breakers are installed in O-2 structures in the plant of the Buffalo General Electric Company, auxiliary channel irons being utilized to take up the difference in width between the two sizes.

The type O oil circuit breakers are particularly adapted to the control of systems of large capacity from 40,000 up to 100,000 turbo-generator K.V.A. where voltages do not exceed 25,000 volts.

This line supplements the type E line of cell mounting breakers, providing higher current and interrupting capacities. These breakers are supplied in single-pole unit form for cell mounting only, each pole being mounted in a separate masonry compartment. The operating mechanism is mounted on the top of the cell structure on a channel and plate base, and operates the several poles as a single unit.

Tanks.—The tanks are cylindrical in form, seamless, and with rounded base, being die pressed from heavy sheet steel. They represent the strongest form of tank construction possible. Type O-1 tanks are 16 inches in diameter, and type O-2 tanks 20 inches in diameter. These breakers are built in the following sizes, all cell mounting, electrically operated only, in 2-, 3-, or 4-pole forms.

RATINGS

Type	Maximum Amperes		Maximum voltage	Interrupting Capacity in arc amperes at rated voltage
	60 cycle	25 cycle		
O-1..........	600	750	25,000	9,600
O-1..........	1,200	1,400	25,000	9,600
O-1..........	1,600	1,800	15,000	18,000
O-2..........	2,000	2,400	25,000	12,300
O-2..........	3,000	4,000	15,000	23,000
O-2..........	4,000	5,000	15,000	23,000

These breakers are electrically operated by the solenoid mechanism mounted on the cell top. The breaker is closed by a solenoid and is held closed by a hardened steel latch and a trigger which engage automatically. The closing solenoid is regularly furnished for use on 125-volt (normal) direct-current circuits and has a standard operating range from 70 volts to 140 volts. Coils for other than standard voltage with the same proportionate operating range can be supplied on special order. Due to the wide operating range, breakers with the standard coil can be satisfactorily operated from 110-volt direct-current circuits.

Acceleration.—In all the type O breakers, an accelerating spring is provided as part of the complete breaker mechanism to assist in forcing the breaker to the open position; an air cylinder dashpot in the lower portion of the spring container takes up the shock of the moving parts. The action of this dashpot can be adjusted by a screw needle-valve which regulates the size of opening of the dashpot valve.

The high interrupting capacity rating of these breakers is due to the form of tank, the use of steel supporting flanges with steel bolts, steel tops, large volume and head of oil, liberally designed arcing tips and the rapid acceleration of the moving contacts when opening.

Oil gauges of the sight-glass form are supplied on each tank so that proper maintenance of the oil level is assured with reasonable degree of inspection. Drain valves are supplied on all forms of this breaker so that when desired, the tanks can be emptied before lowering.

Tanks.—The tanks are deep, providing ample space above the oil level as an expansion chamber for the arc gases and to reduce slopping of the oil from internal disturbances. The gases are vented through specially designed check-valves, providing full venting of gases, but at the same time preventing passage of oil.

Arcing contacts of the spring-actuated, butt type protect the main current-carrying contacts. Each part can be easily replaced at little expense. The arcing contacts open only after the main contacts have separated a considerable distance. As they are placed outside the main contacts so that the magnetic blow out effect of the current will blow the arc away from them, the main contacts are fully protected from any possibility of arcing.

A modification of the design permits these breakers to be made for frame mounting and the mechanism can be placed on the floor at one side or in any of several different locations to suit the desired arrangement of the station.

Specially wide spacing has been used in a few particular cases where breakers were used with bus reactors and the pole spacing was to match that of the reactors.

Type CO.—Where great compactness and high rupturing capacity is desired the CO line can be used, these being essentially O-1 or O-2 poles with a simple compact mechanism something like that of the type C.

The type CO oil circuit breakers in general perform on circuits of not over 15,000 volts, the same service as the type O line, but in more compact space. They have a unit-type electric operating mechanism, forming part of an entirely self containing breaker as shown in Fig. 90 which requires no intermediate walls in the cell structure for supporting individual poles. The complete breaker is shipped in one piece, except for the doors and barriers, with all adjustments of contacts and mechanical parts locked, thus reducing the installation work.

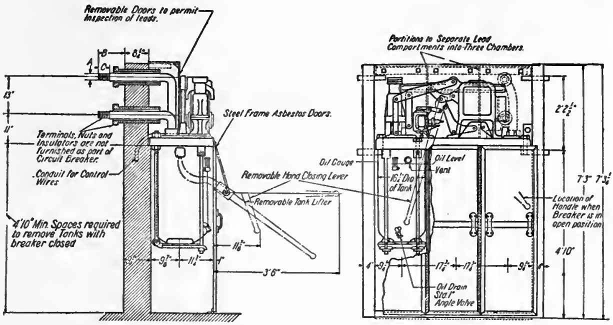


Fig. 90.—Westinghouse oil circuit breaker type CO1.

Ratings.—The following sizes are built only in 3-pole electrically operated cell mounting form.

Type	Maximum Amperes		Maximum volts	Interrupting Capacity in arc amperes at rated voltage
	60 cycles	25 cycles		
CO-1.	600	800	15,000	18,000
CO-1.	1,200	1,500	15,000	18,000
CO-1.	1,600	2,000	15,000	18,000
CO-1.	2,000	2,400	15,000	18,000
CO-2.	600	800	15,000	23,000
CO-2.	1,200	1,600	15,000	23,000
CO-2.	1,600	2,000	15,000	23,000
CO-2.	2,000	2,400	15,000	23,000
CO-2.	2,400	3,000	15,000	23,000

The type CO breakers are made for mounting in brick, concrete, or steel structure compartments. The two outstanding features of the type CO breaker are its compactness and its ease of installation. No intermediate structure walls are required for supporting the individual poles, all of them being supported from the common steel top. The breaker is supported in the structure compartment by means of anchor plates set in and projecting from the cell walls. The steel top of the circuit breaker rests on these anchor plates and bolts hold it securely in place. The space between the circuit-breaker top and the floor in front of the circuit-breaker tanks is covered with removable doors. Three doors are furnished with each standard 3-pole breaker. Each door consists of a metal frame with asbestos panels and is hinged at the top to the mechanism base.

Type G.—The type G oil circuit breakers of modern design comprise a complete line of high voltage breakers for indoor or outdoor use. Four forms of these breakers are built, known as types 'GA,' 'G-l,' 'G-2' and 'G-11.' Each form has a different interrupting capacity with corresponding differences in construction.

The type G breakers all have the condenser type of terminal bushings, steel tanks with welded seams, and large expansion chamber with baffled vents for the arc gases.

All type G breakers can be had in automatic or non-automatic forms. Automatic overload tripping can be obtained either from separate current transformers or from bushing type current transformers which are slipped over the breaker terminal bushings.

Sizes.—These breakers are available for all voltages from 22,000 to 155,000 indoor or outdoor, manual or electrically operated. They are available for frame mounting up to and including 73,000 volts. With interrupting capacities of from 1440 to 5350 arc amperes per phase at rated voltage available with different types, the requirements of present high voltage systems are well met with this line of breakers. Practically all such breakers are arranged for solenoid operation as 3-pole units and are built with a separate steel tank for each pole of each breaker. Usually these steel tanks are so arranged that their spacing may be made to suit the wiring of the installation in case the minimum spacing normally used with the breakers would introduce undesirable bends in the wiring.

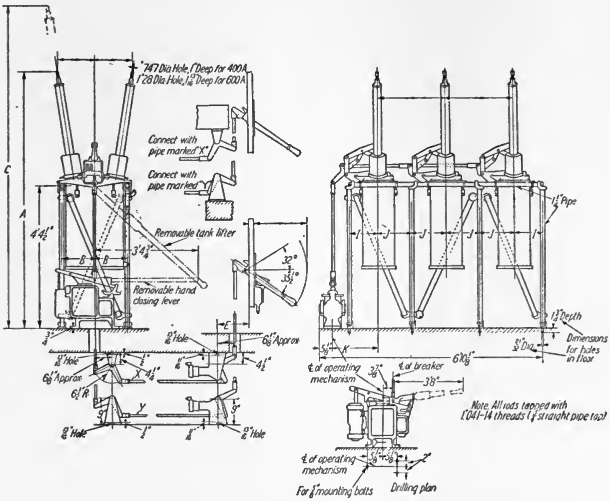


FIG. 91.—Westinghouse 37-K.V. oil circuit breaker type G11.

FIG. 92.—Westinghouse 154-K.V. oil circuit breaker type GA.

Indoor-outdoor.—All of the high tension breakers can be made suitable for either indoor or outdoor service but are usually supplied for outdoor, so most of the illustrations and descriptions will apply to the outdoor type of equipment, but enough indoor apparatus will be illustrated to show the essential differences between the two types.

Up to 73 K.V. the high tension oil circuit breakers whether for indoor or outdoor service are usually made frame mounting to permit the tanks to be easily dropped to secure rapid inspection and adjustment of the contacts.

Indoor.—Fig. 91 shows a 37-K.V. G-11 breaker for indoor service and clearly illustrates the pipe framework used for supporting the breaker at such a height that the tanks can be readily dropped. The highest voltage breaker that has been built for indoor service is shown in Fig. 92 which illustrates the 154-K.V. type GA floor mounted breaker furnished to the Big Creek Power Company a number of years ago.

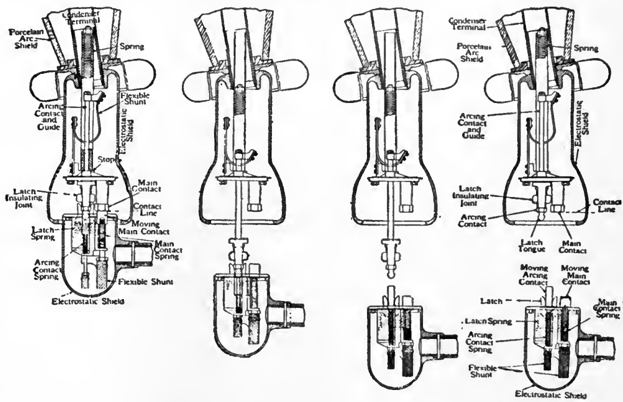


FIG. 93.—Westinghouse type GA oil circuit breaker—contact details.

Quick Break.—Circuit breakers for high voltage service such as these illustrated involve long travel of the contacts and heavy moving elements and therefore are arranged to embody a special quick break feature for the rapid separation of the arcing contact which is so essential on a high power interrupting service.

Fig. 93 shows the contact details employed with the 154

K.V. breaker. The lower end of the condenser terminal bushing is enclosed in a porcelain arc shield for protection from the arcs that arise during operation. Between this arc shield and the stationary contact is a metallic static shield for distributing the stress uniformly over the surface of the terminal bushings. The main contacts are of the butt type, each terminal having two main contacts and two arcing contacts, the latter being designed to take all of the arcing so that the main contact will not become pitted or burned by the arc. The entire stationary contact is enclosed in a metal hood which distributes the electrostatic stress that might otherwise be excessive due to the sharp corners on the edges of the contact mechanism.

Arcing Contact.—The arcing contacts attached to the stationary terminals of the breaker are so arranged that in the closed position they are latched in touch with the corresponding arcing contacts on the movable member. When the breaker opens the main contacts separate at once, but the latch holds the arcing contacts together, forcing the upper one to be pulled down against the compression of a spring for a distance of approximately 7 inches. After the moving member has dropped the 7 inches, the latch releases and the spring retrieves the upper arcing contact, breaking the circuit very quickly.

The break in the circuit occurs in the free oil and the natural tendency of the gas bubble to rise is not in any way impeded. The magnetic effect of the current passing down one stationary contact across the moving member, and back the other stationary contacts is such as to blow the oil away from the contact and toward the side of the case. This effect together with the natural tendency of the gas bubble to rise through the oil enables the arc to be quickly carried away.

While the descriptions that follow apply to outdoor breakers, corresponding indoor breakers differ only from the outdoor ones in the omission of the rain shields from the condenser bushing terminals and certain minor changes in the housing of the mechanism and the venting of the tanks.

37 K.V.—Fig. 94 shows a 400-ampere 37-K.V. 3-pole solenoid operated frame mounted outdoor breaker with one tank removed to show the contacts. This breaker has a guaranteed rupturing capacity of 1700 amperes at 37 K.V. With the frame mounting it is possible to drop the tank on any one pole to obtain ready access to the contacts.

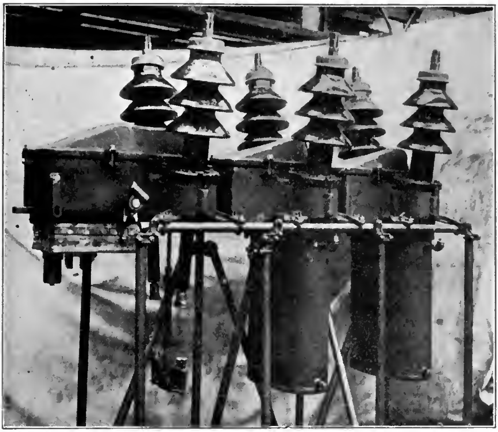


Fig. 94.—Westinghouse type "G-11" outdoor oil circuit breaker, 400 amps. 37 K.V.

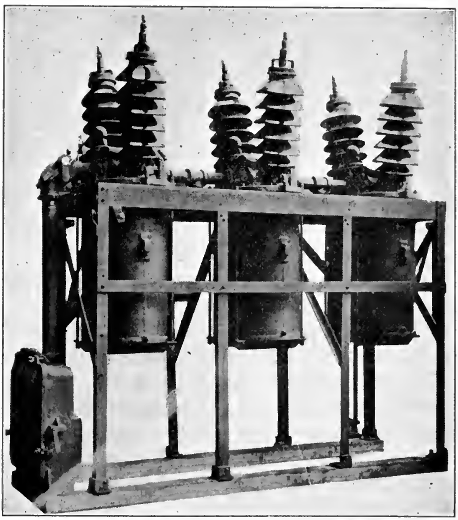


Fig. 95.—Westinghouse type "G-11" outdoor oil circuit breaker, 400 amps., 73 K.V.

73 K.V.—Fig. 95 shows a 400-ampere 73-K.V. solenoid operated outdoor frame mounting oil circuit breaker having a guaranteed rupturing capacity of 2400 amperes at 73 K.V. This breaker has elliptically shaped oil tanks made of.steel plate with lap-welded seams and a cast steel top of domed shape to secure ample strength against explosion. The tanks are arranged for suspension from the supporting frame and are hung by suitable tie bolts connected to a supporting grid beneath the tank. An overhung lip around the top is interlocked with the tank rim and suitable packing between the top and the rim insures waterproof joints. A suitable removable cover with interlocking rim gives access to the upper portion of circuit-breaker mechanism. Conduit pipe with packing washers and lock nuts affords weatherproof communication from pole to pole for the operating levers and for the control leads when required. Solenoid operated mechanism is located at one end of the unit, housed in a case or box with a removable cover having packed joints. This box has conduit pipe for connection to the circuit-breaker mechanism.

The steel top in addition to supporting and protecting the operating mechanism is arranged to form an expansion chamber to cushion the pressure caused at the instant of interrupting the circuit. As considerable oil vapor and gas may collect in this chamber, suitable baffled vents are placed in such positions as to relieve sudden air pressures, and in addition, to induce circulation of air through the chamber to drain out the accumulating oil vapor. As the oil is of more or less volatile nature, this latter function is of considerable importance. To prevent the transmission of a disturbance in one tank to adjacent tanks and to the box containing the operating mechanism and solenoid, suitable baffles can be placed in the connecting conduit pipe. Pressure can be vented to the outside, but propagation of pressure from tank to tank will be prevented.

The terminal bushings are sufficiently protected by petticoated insulators to afford insulation under the most severe conditions of driving rain, wet snow or sleet. It is not uncommon to find the entire structure, including the exposed portions of the porcelain insulators, incased in a coating of sleet, or to see snow piled up practically to the entire height of the terminal bushings.

Frame Mounting.—On circuit breakers of small and moderate size where the weight of the oil tanks and oil is not prohibitive, the frame mounting arrangement of circuit breaker is highly desirable as it permits the ready removal of the oil tanks for the purpose of inspecting the contact details and the operating mechanism without disturbing the line connections.

Platform Mounting.—Breakers for higher voltages and larger rupturing capacities are usually made platform mounting owing to the difficulty of lowering the tank filled with oil.

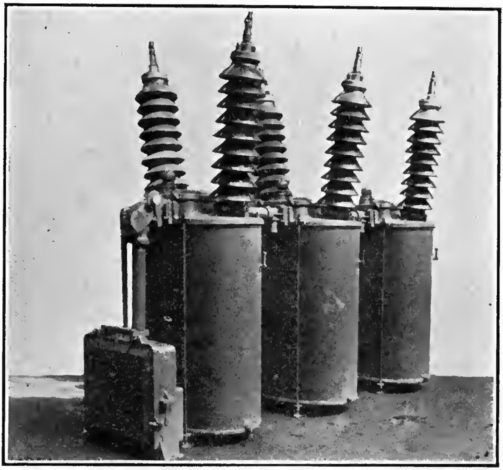


Fig. 96.—Westinghouse type "G-11" outdoor oil circuit breaker, 400 amps., 95 K.V.

With the larger breakers access to the interior of the tanks is secured by the removal of the mechanism cap which exposes the lever system and presents a sufficiently large opening to withdraw any necessary part. The mechanism is ordinarily so arranged that a terminal bushing complete with its contact details can be withdrawn without disturbing any other details, and the moving contact elements can also be withdrawn through the manhole or mechanism cover.

Experience has indicated the desirability of providing a structural frame or platform that will permit access to the bottom of the tank, allowing free air circulation as this assists in keeping all parts free from rust and corrosion.

In certain cases the tank bases are made with openings in the rim so that the bottom of the tanks can be painted with a long-handled brush if the foundation is of concrete or masonry that would otherwise make it difficult to get at the bottom of the tanks.

Platform Type.—A typical outdoor platform mounted breaker is shown in Fig. 96 which illustrates a 95-K.V. 400-ampere breaker with elliptical tanks having a guaranteed rupturing capacity of 2400 amperes at 95 K.V.

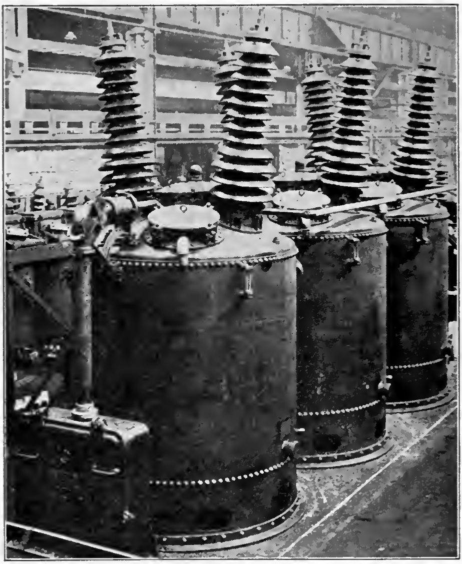


Fig. 97.—Westinghouse type "G-2" outdoor oil circuit breaker, 400 amps., 135 K.V.

Type G-2.—The type G-2 oil breaker is of "all-steel construction" and has a tank of the strongest possible construction. The shape of the tank is cylindrical with spheroidal top and bottom, having the same radius of curvature as the sides. This form of tank having all seams riveted is tested to withstand a static pressure of 150 pounds per square inch. The steel top and bottom are flanged inside and riveted to the tank body, completing a form of construction, all details of which are directly comparable to that followed in the best high-pressure boiler practice.

FIG. 98.—Westinghouse type "GA" outdoor oil circuit breaker, 400 amps., 135 K.V.

This construction takes full cognizance of gas pressures which accompany the interruption of high voltage large ampere capacity arcs. Of necessity these pressures are transmitted equally through the surrounding oil medium to the walls of the containing vessel. Due to the voltage and power of the arc, reliance is placed on a large head of oil aiding the natural buoyancy of gas bubbles to present an ever changing mass of cool and clean oil to the arc while at the same time the mechanical strength of the containing vessel is made ample to withstand pressures that may be transmitted from the arc through the oil medium. Past operating experience with high powered moderate voltage systems has shown the danger involved in trying to confine this arc to too small a vessel with a low head and small volume of oil. This is particularly true when recognition is given to the demands of modern operation for a breaker to be capable of opening its rated interrupting capacity in arc amperes twice within an interval of two minutes.

The large size of these circular tanks with the consequent immense volume of oil, strength of materials and construction, depth of contacts below the oil level and the rapidity with which the contacts are opened, result in a breaker entirely adequate for the largest power systems.

Fig. 97 shows a 400-ampere, 135-K.V., 3- pole breaker having a guaranteed rupturing capacity of 4300 amperes per phase at 135 K.V. This breaker was furnished to the West Penn Power Company for 132-K.V. service and a modification of it is available for 155-K.V. service

Type GA.—Fig. 98 shows the 400-ampere 135-K.V. electrically operated oil circuit breaker having a guaranteed rupturing capacity of 1600 amperes at 135 K.V. A number of these breakers are in service in Michigan.

Designs have been prepared for breakers for use on 220-K.V. circuits, and some are now being built.

CHAPTER V

RELAYS

Functions.—Modern distributing systems require protection more selective and flexible than that afforded by the usual control features of automatic circuit breakers and this need is supplied by automatic devices known as relays which trip a circuit breaker upon the occurrence of some predetermined change.

Types.—Relays are built to furnish protection on A.C. or D.C. circuits against overvoltage, no voltage, overload, no load, reverse load and reverse phase and such relays either directly or in connection with other relays may be made instantaneous or provided with a time limit either of definite duration or inversely proportional to the extent of overload, etc.

Definite Time.—This type is used with circuits where the service must be maintained at all hazards no matter how great is the overload provided it does not last more than a definite period of time say from 2 to 4 seconds, depending on the ability of the system to withstand such conditions and the length of time required for various feeder breakers to trip out, relieving the system protected by the breaker with definite time limit.

Inverse Time.—This relay gives a selective action varying inversely with the load so that usually the faulty line carrying the heavier load will have its breaker tripped out before the other breakers are affected.

D.C. RELAYS

Overload.—The D.C. overload relays of the Condit Electrical Manufacturing Company are made with series coils in the form of a solenoid for current ratings from 5–600 amperes as shown in Fig. 99. For currents from 800–3000 amperes the magnetic circuit is arranged to slip over a round stud while for currents from 800–8000 amperes the magnetic circuit can be put around the copper strap connections in the leads or bus. These relays are made as instantaneous or with inverse time limit features.

A modification of the arrangement is made by the addition of the voltage coil that changes the relay to a D.C. reverse power relay with the current element to slip over a circular stud.

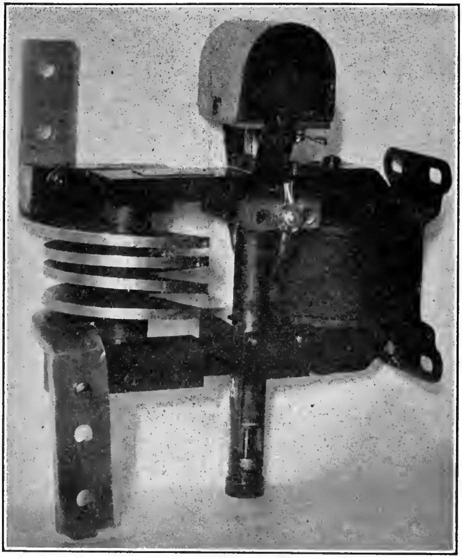


FIG. 99.—Condit Electric & Mfg. Co. type "DC" relay.

Reverse.—When an adjustable reverse-current D.C. relay with time limit is desired, a type of relay is used built on the principle of a permanent magnet D.C. ammeter operated from a shunt. In normal operation the armature of the relay tends to turn in one direction but is restrained by a stop, while in the case of reversal the armature turns in the opposite direction, its movement being restrained by a spring and being proportional to the strength of the current in the reverse direction. The angle through which the armature has to turn to close the contacts is adjustable by moving the stationary contact. The inverse time element feature is obtained by the movement of the aluminum frame, on which the armature is wound, in the intense magnetic field, the eddy currents in the frame furnishing the damping action. A modification of this design is used for D.C. overload relay.

A.C. RELAYS

Overload.—One of the simplest overload A.C. relays designed for instantaneous operation, definite time limit and inverse time limit, consists essentially of a solenoid and core. In the instantaneous relay the core lifts immediately and closes or opens contacts that trip the circuit breaker when the current in the coil reaches a certain value. With the inverse time limit the movement of the core is opposed by a bellows with an adjustable valve mounted above the coil. With the definite time limit the same kind of bellows and valve is used but the solenoid does not work directly on the bellows. When the overload occurs the core rises instantly compressing a spring which in turn acts on the bellows. If the core, due to continued overload, keeps the spring in compression the required time, the air will be forced out of the bellows and the tripping circuit operated. This type of relay can be set for any time limit between 1 and 10 seconds. Relays of this type are usually operated from current transformers but are sometimes mounted on a high tension insulator and connected in the high voltage circuit. This plunger type of overload relay has been practically superseded by the induction type.

Radial System.—The proper relaying equipment for use on any A.C. line will depend among other things on the type of distribution used. Where there is a single source of power with feeders radiating out from the generating station and possibly passing through one or more sectionalizing or transforming stations, proper selective action can usually be obtained by making the breakers farthest from the power house practically instantaneous in their operation, those at the power house being provided with relays set for a definite time of from one to two seconds and the intermediate sections being provided with relays having various time settings.

Current Settings.—In addition to securing discrimination on the part of the relays by means of a definite time feature, it is also possible to discriminate by the current setting because trouble which occurs at the far end of a branch line will not draw as heavy a current as though it were closer to the source of power. Selective action can frequently be obtained to advantage by the use of an inverse time limit relay having characteristic curves similar to those shown in Fig. 100. This type of relay has an adjustable definite time element in addition to the inverse time, and the combination of these two is well adapted for the protec-

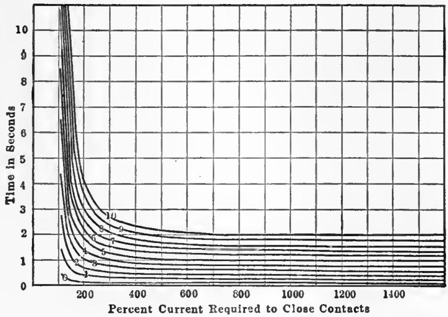


Fig. 100.—Relay characteristic curves.

tion of circuits of this kind, because either the inverse time part of the curve or the definite time part can be utilized, dependant upon the particular circuit standard.

Type CO.—Such a combination of definite time and inverse time is obtained in the type 'CO' Westinghouse relay shown in Fig. 101. This relay is built on the induction principle, and its great success has been largely due to its remarkable accuracy and permanence of its calibration. The use of a permanent magnet as a time limit device, prevents over swinging and chattering of the contacts, and the construction is such that the relay will instantly cease its movement when the over load disappears.

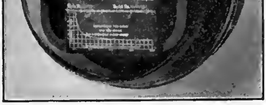


Fig. 101.—Westinghouse type CO definite minimum inverse time limit overload relay.

Torque Compensator.—One of the essential features of this relay is the torque compensator embodied in its design. This is essentially a small current transformer having comparatively little iron in its magnetic circuit so that it saturates at a little more than 5 amperes in the primary. With this device the primary current can be momentarily increased to 200 times normal without increasing the secondary current more than a small percentage. As it is this secondary current that actually works on the relay mechanism the force of the relay is practically constant, independent of the amount of the current, so that its speed of operation is independent of the value of the short circuit and is determined by the restraining influence of the permanent magnet and the distance through which the contact has to move. As this distance is adjustable, the definite time setting on the standard relay can be made anything from 0.1 of a second up to 2 seconds, and in special cases up to 4 seconds. A current adjustment is also provided on the relay so as to secure normal operation with relay current varying from 4 to 12 amperes.

Parallel System.—Where the distributing system instead of being a radial one is provided with parallel circuits between the generating stations and the points of distribution, such systems can sometimes be protected satisfactorily by means of inverse time element relays if the short circuit conditions are such that relays of this type can properly discriminate, but the more usual method of protecting service against trouble on parallel feeders is to place reverse power relays at the substation end of each feeder and definite time limit relays at the generator end.

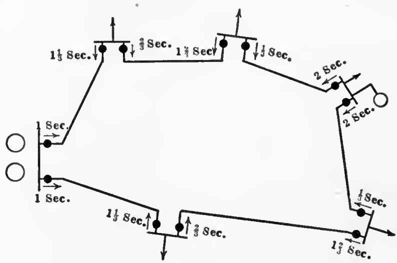


Fig. 102.—Ring arrangement of circuits.

Ring System.—A modification of the parallel feeder arrangement is the ring system where each substation is fed from two directions, as indicated in Fig. 102. On such a system definite time limit reverse power relays must be utilized and the time setting of each successive relay should be increased by a sufficient amount to allow time for the circuit breaker in the preceding substation to open. On the diagram the time settings of the various relays have been marked and for ⅓-second time interval will work satisfactorily if the relays are accurate and the circuit breakers quick acting. Such a system becomes somewhat more complicated if power is fed in at more than one point, as for example if a generator ties in at station D. The adjustment of the relays on such a system would have to be modified depending on whether the power was being generated at A or at D so that it is evident that relays are desirable whose adjustments can be quickly changed.

Reverse Power.—For the protection of a parallel feeder system or a ring system, reverse power relays are necessary and these are made by the Westinghouse Company in the form of a two element relay, the current element being practically the same as that of the 'CO,' and having the same overload and time element characteristics. In addition to the current element there is a watt element that closes a contact whenever the flow of energy is in a reversed direction from the normal one. The current element closes its contacts on excess current in either direction, but the relay will not function to trip the circuit breaker unless the selective wattmeter element also functions due to the power being in the reversed direction.

While in many cases transmission and distribution systems can be readily sectionalized by the standard application of overload and reverse power relays, there are other conditions that can best be handled by a balanced system of relays.

Balanced System.—This system, utilizing pilot wire schemes and standard overload relays, operates from the secondaries of current transformers placed at two ends of the feeder, but such an arrangement requires conductors to be run between these current transformers and, ordinarily, on long distance transmission lines, such an arrangement is not very practicable.

Split Conductors.—A split conductor scheme can often be utilized to advantage where the power to be transmitted is such as to required two conductors in parallel. In most cases, however, an arrangement of balancing relays on parallel feeders using the cross connection of reverse power relays will work out to the best advantage.

Balanced Relays.—Such an arrangement is indicated in Fig. 103, this showing four circuits between a generating station and receiving station. This schematic diagram has been simplified by showing only one phase on each of the feeder circuits. By reference to these two figures it will be noted that the current transformers at the generating station are connected in series for each particular phase and similarly at the substation, and that each relay, that must be of the reverse power (uni-directional) type, is shunted across its own current transformer.

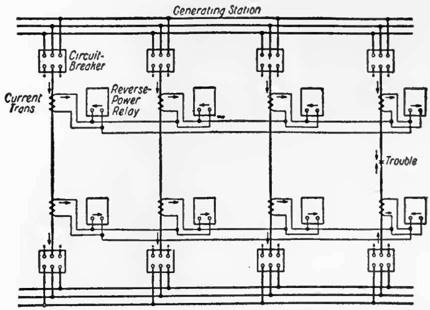


FIG. 103.—Balanced arrangement of relays.

Under normal conditions the load in each of the parallel feeders will be the same, and since the relays have a higher impedance than the current transformers, the current from the latter will circulate through all of them in series without any flowing through the relays. If the trouble occurs at any point outside the section protected by the cross connected relays, the current over the feeders will still be balanced and consequently there will be no force tending to operate the relays. In other words, a short circuit occurring on some other portion of the system will have no tendency to trip out any of the breakers in this section.

On the other hand if trouble occurs at a point within the protected sections, the current over the defective circuits will be higher than that in the others, and this excess current from its current transformer must pass through the relays. While under this unbalanced condition, current will flow through all of the relays, it will be observed that the current is in the proper direction to cause the relays to act only at each end of the defective section as shown by the arrows in the diagram.

Pallet switches are connected in the transformer secondary circuit and are mechanically operated by the breaker so that when the breaker opens the current transformers are short-circuited. By this method, a feeder can be cut out of service without interfering with the electrical balance in the current transformer circuits.

Double Contact Relays.—Where there are only two parallel feeder circuits, a double contact reverse power relay can be utilized. This relay is so arranged that in case of trouble, the watt element will close the circuit leading to the trip coil of the breaker in the defective circuit, and the excess current element will operate to trip out that breaker under suitable conditions of overload and time element.

More complicated networks can usually be taken care of by proper selection of the type of relays to be employed. It frequently happens that the problem of automatic sectionalizing can be very much simplified if, at the instant of short circuit, a number of circuit breakers are opened for the purpose of simplifying the operation of the remainder of the systems.

These induction type relays of the Westinghouse Company have their characteristic curves marked on their nameplates. The corresponding relays of the General Electric Company have the information in the form of tabulated data on their nameplates. All of these induction type relays utilize many of the parts of the induction type watt-hour meters of the respective makers.

The inverse definite time limit relays of the Condit Electrical Manufacturing Company have many features similar to those mentioned above, except that they do not use any power consuming retarding element, such as bellows, dashpot, magnetic drags, etc. The current adjustment is obtained by means of a calibrated compression spring and the time adjustment is obtained by moving the contact arm into various positions on the worm wheel.

The usual sectionalizing relays are intended for disconnecting defective feeders and are not primarily intended to protect apparatus in case of overload. The current settings of such relays are generally a function of the current flowing under short circuit and are thus higher than required for protection against sustained overload.

Temperature Relay.—This may be used to protect any alternating current apparatus from excessive heating if the apparatus is so arranged that exploring coils can be installed. The relay is intended to protect apparatus against overheating from sustained overloads. To afford this protection with the least interruption of service the breaker should be tripped through the direct effect of the temperature of the apparatus. The relay should be so arranged that it prevents the breaker from tripping if the overload is of such short duration that the temperature does not rise to a dangerous value; while, if the overload persists, the breaker must be tripped out as soon as the temperature rises beyond the critical value. This is accomplished as follows:

Principles.—The temperature relay operates on the Wheatstone bridge principle. Two arms of the bridge are copper exploring coils arranged to be placed in the oil or embedded in the windings of the apparatus to be protected, the other two arms are unchanging resistance mounted in the relay. The current for the bridge is supplied by the current transformer connected in the circuit of the apparatus to be protected. The relay has two windings, corresponding to and co-operating to produce torque in a manner similar to the current and voltage coils of a wattmeter. The main winding is a coil operated directly by the current transformer. The auxiliary coils are connected to the Wheatstone bridge arms similarly to a galvanometer connection, and thus receive current the magnitude and direction of which depends upon the resistance of the search coils. Above a certain temperature the torque of the relay is in the contact direction and below, in the opposite direction. It will thus be noted that, in order to close the contact, two predetermined conditions must co-exist: excess current, and excess temperature. Neither one will separately trip the relay.

Transfer Relays.—These are used with protective relays that operate on excess current where a direct-current trip circuit is not available. They energize the trip coil of the circuit breaker through current transformers.

The breaker operates solely through the current transformer and the relays. When there is no fault on the line the trip coil of the breaker is mechanically and electrically isolated from the circuit, avoiding possibility of tripping due to imperfection in the relay contacts ordinarily shunting the trip coil.

The relay contains two series coils, an upper or operating coil and a lower or holding coil (see diagram of connections, Fig. 104). The holding coil holds down the armature core, until a third coil, wound on the same magnetic circuit and known as the releasing coil, is short-circuited by the protective relay. The releasing coil acts as the secondary of a transformer and when short-circuited, a current flows through it, demagnetizing the core. The holding coil, therefore, allows the operating coil to raise the core which operates the transfer switch, thus closing the trip coil circuit.

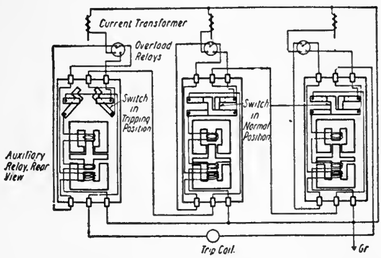


Fig. 104.—Transfer type relay.

The transfer switch and other current-carrying parts of the relay are designed to carry 5 amperes continuously, but during time of short circuit the switch may be called on to handle as much as 100 or 200 amperes.

A current transformer must be selected of sufficient capacity to operate the protective relay, the transfer relay, and the trip coil. Low ratio bushing type current transformers sometimes used on high voltage circuit breakers are not suitable.

Only one trip coil is required for use on a polyphase circuit, but if the breaker is equipped with as many trip coils as there are relays, it is advisable to connect each trip coil to its corresponding relay.

Bell Relay.—This provides an alarm to notify the attendant that a circuit breaker has tripped automatically. It is generally mounted behind the switchboard. This relay operates the alarm when the tripping is due to the action of automatic tripping devices, but does not operate when a circuit breaker is opened intentionally. The alarm can consist of a bell or other indicating device. The relay action is such that the alarm continues until stopped by pushing a button.

The bell relay consists of a contact-making armature actuated by an electromagnet excited by two windings. One winding is in series with the automatic trip circuit. When automatic tripping occurs, current passes through this winding and the armature is attracted, closing the bell circuit. The other winding is in parallel with the bell circuit, so that when the bell circuit is closed this second winding holds the armature and does not permit the circuit to open when the trip circuit has opened with the circuit breaker. The bell circuit is opened by means of a push button provided for this purpose, whereupon the armature of the relay opens contact.

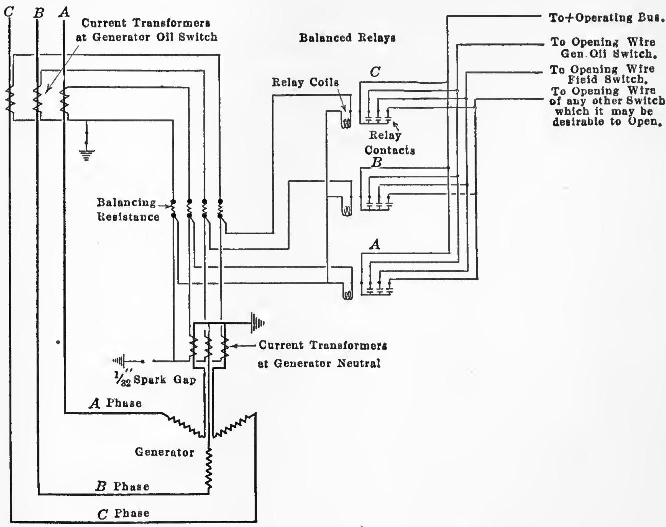


Fig. 105.—Schweitzer & Conrad multi-circuit relay.

S. & C. Relay.—The multiple circuit sensitive relay of Schweitzer and Conrad is used where it is desirable to have a relay that will operate on very small currents and yet have contacts that will carry sufficient current to operate remote-control circuit breakers, field circuit breakers, blower motor circuits and the like. This is accomplished by having a relay provided with a weighted arm that has its weight just beyond the center so that very little energy is needed to carry it past the center and allow it to fall into the position where it will close the necessary number of auxiliary circuits. This type of relay can be used to advantage in connection with the Merz-Price system of differential protection.

With this scheme, the relays are connected between the three-phase pilot wires and the neutral pilot wire connecting the secondaries of the neutral current transformers to the secondaries of the terminal current transformers. The relays are connected at the electrical centers of the pilot wires. The balancing resistances shown in the diagram are necessary in order to be able to connect the relays to the pilot wires at the electrical center, as in most cases it would be impractical to connect them midway between the two sets of current transformers.

Connections.—The scheme of connections shown in Fig. 105 provides for only three relay contact circuits. A favorite arrangement with large generators is to use a four-circuit relay to open the two generator oil circuit breakers, the field circuit breaker and blower motor circuit breaker.

With the circulating current system of generator protection the relays are not affected by an unbalance of current in the different phases, or by overloads and external short circuits no matter how great, or by reverse power, provided the connections are made as shown and the balancing resistances are of the proper value. In other words, the relays will operate only in case of a ground or other fault occurring in the generator windings or on the leads between the neutral current transformers and the terminal current transformers. Furthermore, they will operate on such small currents and so quickly that they will disconnect the generator from the system and open the field circuit before material damage is done at the point of breakdown and with a minimum of disturbance to the system itself.

Series Relay.—In high voltage stations requiring overload protection and where the extra cost of separate current transformers has prohibited the use of accurate relays, the high voltage series relay shown in Fig. 106 has been an economical substitute affording ample overload protection and an approximate time element. These relays have been used chiefly for circuits of 100 amperes or less; for heavier currents the use of ring type current transformers built around the circuit breaker bushings and operating induction relays will be found more convenient. Series relays are for indoor use and are suitable for any frequency.

The relay coil is inserted in the high voltage line, but the contacts and timing parts are insulated and can be handled, adjusted, or tested without disconnecting the feeder. The coil can be mounted on a disconnecting switch or choke coil without separate insulators, and the contact mechanism mounted in the position most convenient. A solenoid mechanism operates a timing and circuit-closing element through a wood rod or micarta chain of such length as to provide ample insulation for the voltage in use.

Two forms of series relays are furnished: inverse time element and definite time element. The inverse time element relay can be set for practically instantaneous tripping.

Inverse Time.—In this relay the solenoid and chain are opposed in their motion by a bellows with an adjustable valve. The valve has a small numbered dial which permits of any setting between a maximum time element of about 20 seconds at 25 per cent. overload and a minimum of about 1 second at the same overload. With greater overload the relay acts in a shorter time.

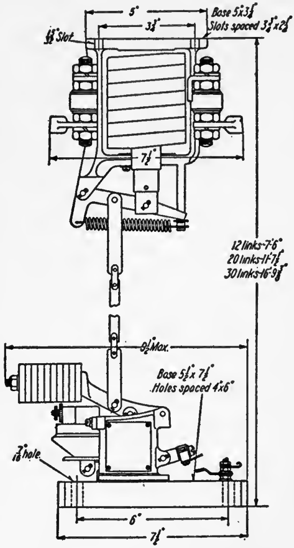


Fig. 106.—Series type of relay.

Definite Time.—In this relay the same kind of bellows and valve are used as for the inverse time element, but the solenoid chain does not act directly on it. The core and chain rise instantly when the current reaches the tripping valve, and compress a spring. The spring in turn acts on the bellows. If the overload continues for the time for which the relay is set the tripping contacts close. The time required for the spring to close the contacts depends only on the setting of the valve, and is entirely independent of the magnitude of the overload. The relay can be set for any time element between 1 and 10 seconds.

The minimum current at which the relay will trip depends on the number of weights placed on the arm of the contact making mechanism. This can be varied from 80 per cent. to 160 per cent. of the rated current of the relay.

These relays are not as accurate as to time element as the magnetically damped relays. Their time element will be found sufficiently accurate to afford protection on the circuit to which applied, but selective protection with regard to other circuits in the system cannot always be satisfactorily obtained with a bellows relay.

The circuit breaker should have auxiliary contacts to open the trip circuit when the breaker opens, relieving the relay contacts of this duty.

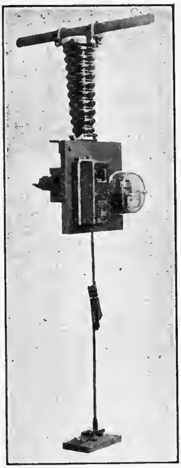


Fig. 107.—Westinghouse high voltage induction type relay.

One relay is required to protect a single-phase circuit, two relays for a 2-phase or 3-phase ungrounded neutral circuit, and three relays for a 3-phase grounded netural circuit.

An insulating support for the relay element is not furnished separately as the relay is intended to be mounted on the disconnecting switch pillar or other support of the high voltage line. Where required a bracket support complete with insulator and necessary mounting plate can be supplied.

High Voltage Induction.—Fig. 107 shows the latest modification in this type of equipment where the series solenoid is replaced by a low voltage series transformer, an accurate induction type relay and a transfer type relay, all of these devices being mounted on a small panel, the latter being supported by a high voltage insulator. The current transformer and induction relay permit very accurate relay settings with adjustable definite time delay from 0.1 to 2 seconds, and current settings from 4 to 12 amperes. The operation of the induction relay serves to close the circuit of the releasing coil of the transfer relay. This transfer relay is connected through a micarta insulating chain to the switch whose contacts, on closing, cause the electrical tripping of the breaker.

With certain changes this type of relay has been made suitable for outdoor high voltage service.

CHAPTER VI

SWITCHBOARD METERS

While this chapter deals particularly with instruments, their detail design will not be touched on but some general information will be given relative to meters and their various functions in connection with switchboards.

Compactness.—This is one of the essential features of switchboard meters owing to cost of panel space, reduction in attendance and visibility of all instruments from one point of operation. While securing compactness, length of scale has not been lost sight of in design and this length of scale varies greatly in instruments of different designs occupying approximately the same amount of space.

Accuracy.—While this is of great importance it is necessary to distinguish between the accuracy that is desired in laboratory instruments and the accuracy which can be obtained in switchboard meters without sacrificing other essential qualities such as ruggedness, sensibility and accessibility. For switchboard work it is better to secure instruments that will stay accurate within 2 per cent. with an initial error of 1 per cent. than to use meters whose initial error is only a small fraction of 1 per cent. but which will not remain within 2 per cent. when used in actual switchboard work where the magnetic stresses resulting from system short circuits are apt to damage a very sensitive meter. High accuracy and ruggedness are more or less antagonistic qualities and a satisfactory compromise is an initial error of about 1 per cent. and a final error in actual service of less than 2 per cent.

D.C. Meters.—For direct-current service the cheaper grades of meters are made of the moving iron type while the better grade of ammeters and voltmeters are of the D'Arsonval permanent magnet construction. When the meters are so designed that the movements can be readily removed without disturbing the magnetic circuit by the removal of the pole pieces they are particularly suitable for switchboard service.

A.C. Meters.—For A.C. service the indicating instruments are made as "moving iron," "moving coil" or "induction" type and the relative advantages and disadvantages of these types are as follows:

Moving Iron.—This electromagnetic type of meters has good initial accuracy and is approximately free from temperature and frequency errors and is easy to repair. Unless heavily shielded they are subject to external fields and their scale length is short.

Moving Coil.—This electrodynamometer type is free from errors due to temperature and frequency variation and can be made with very high initial accuracy. They are usually delicate and difficult to repair, have short scale lengths and are subject to external fields of same frequency unless heavily shielded by internal laminated iron shields.

Induction Type.—These meters have good initial and service accuracy, rugged and simple movements, extremely long and easily read scales and are easy to repair. The frequency error is greater than in the other types and they are subject to slight errors from external fields only when of the same frequency and in certain directions.

D.C. Ammeters.—Direct-current ammeters of the moving iron type are built for connecting directly in the circuit in capacities up to about 600 amperes while the permanent magnet meters are made in all capacities and are usually operated from shunts having a drop of approximately 50 millivolts.

D.C. Voltmeters.—D.C. voltmeters of any type are connected directly across the circuit in series with a resistance or are connected across a portion of the resistance in such a way that their scale reading gives a correct indication of the pressure. As most D.C. plants whether for railway or for light and power service are operated at practically constant potential the voltmeters are depended on as a guide to the operators in maintaining the proper pressure.

A.C. Voltmeters.—These are usually wound for connecting directly to the circuit for pressures up to approximately 750 volts and beyond that point are operated from voltage transformers usually with a 100-volt secondary. These voltmeters are frequently marked with scale corresponding to primary voltage of the transformers, and have coils that will stand 150 volts. For example, the voltmeter used with the 6600-volt circuit would probably be operated from a transformer having a ratio of 6600–110 volts and would be provided with a scale of 9000 volts.

A.C. Ammeters.—Certain types are made in capacities up to about 300 amperes for connecting directly in the circuit unless the voltage is high, but the better grades of instruments are operated from current transformers usually having a secondary current of 5 amperes. The scale reading of the meter is usually made to correspond with the primary capacity of the current transformer. Arrangements can usually be made so that one A.C. ammeter can be operated from any number of current transformers, so as to read the current in any circuit.

Wattmeters.—On A.C. generator panels and sometimes on other panels of a switchboard, indicating wattmeters are desirable to show at a glance the output of that particular circuit independent of the voltage or power factor of the circuit. They are particularly useful on A.C. generator panels to facilitate the proper division of the load. On panels for use with synchronous motor-generator sets or tie circuits which may either be taking power from or delivering power to the bus bars, double reading wattmeters with the zero in the center of the scale are recommended.

Watt-hour Meters.—On feeder and load panels and sometimes on generator panels it is often deemed advisable to install watt-hour meters either A.C. or D.C. to record the power supplied to a certain feeder, to one set of bus bars or furnished by one generator. A.C. watt-hour meters can be provided with a recording demand chart to give readings every 15 minutes.

Power Factor.—On panels for control of the A.C. end of synchronous converters and synchronous motors it is advisable to install power factor meters or reactive factor meters as these instruments will show at a glance whether the fields have been adjusted to best advantage or whether the current taken is leading or lagging in character. As the pointer on one design of the power factor meter can move through an arc of 360 degrees it can indicate whether the circuit in which it is connected is delivering power to or taking power from the bus and whether the current is leading or lagging.

Field Ammeters.—These are often supplied for use in connection with generator and synchronous motor circuits to aid in the proper adjustment of the field.

Frequency Meters.—These can often be used to advantage to determine the frequency at which the plant is operating. Where there are two or more sets of bus bars, or several stations feeding into a common transmission line this point is often of vital importance.

Synchronoscopes.—On the better class of A.C. boards it is usual to supply synchronoscopes instead of depending on lamps for synchronizing. These instruments of General Electric or Westinghouse make are so made as to actuate a hand moving around a dial in such a manner that the angle between the pointer and the vertical indicates the phase angle between the E.M.F. of the bus bars and the machine to be connected. If the frequency of the incoming machine is too high, *i.e.*, if the machine is running too rapidly the pointer will revolve in the direction marked "fast" while if the machine is not running rapidly enough the pointer will revolve in the direction marked "slow."

The synchronoscopes of the Weston Electrical Instrument Company are built on a different principle resulting in the apparent movement of the hand across the scale in one direction or the other corresponding to the "fast" or "slow" direction with the pointer stationary at the middle of the scale at the instant of synchronism.

Static Ground Detectors.—For higher voltages static ground detectors are recommended. The Westinghouse types are operated from condensers so that there is no danger from high voltage in the instruments, in case of accidental contact. With the General Electric device, rods of high resistance material limit the current to an inappreciable amount in case of accidental contact.

Graphic Meters.—In addition to the indicating meters described above various manufacturers furnish D.C. ammeters and voltmeters as well as A.C. ammeters, voltmeters, wattmeters, power factor meters and frequency meters that plot a graphic chart either as a circular chart with polar co-ordinates or on a continuous strip with rectilinear co-ordinates. In the first case circular charts about 8 inches in diameter are used, revolving once an hour or once a day or at some other predetermined rate while with the latter type the scale on the chart moves at 2, 4, 8 inches per hour or at any other desirable speed and a record for a month or so can be made on a continuous strip of paper if desired.

GENERAL ELECTRIC INSTRUMENTS

Horizontal Edgewise.—The indicating instruments of the General Electric Company are made in various forms but the usual design for use on large A.C. switchboards is the horizontal edgewise arrangement illustrated in Fig. 108. These instruments

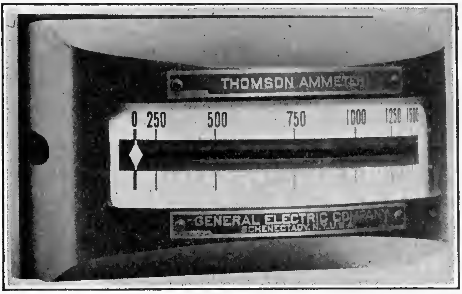


FIG. 108.—General Electric Co. horizontal edgewise meter.

are about 6½ inches high, 8 inches wide and all of the usual types of indicating meters both A.C. and D.C. are made in this form, presenting a very uniform appearance on a switchboard. The A.C. meters are operated from current and potential transformers and the D.C. ammeters either direct in the circuit for moderate capacities or operated from shunts in the larger sizes. These meters are very substantial in their construction and withstand well the short-circuit stresses met with in actual station operation.

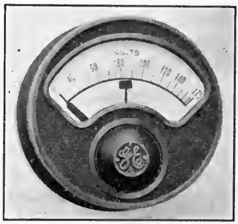


FIG. 109.—General Electric Co. round pattern meter.

Round Pattern.—Round pattern meters are made as ammeters and voltmeters for A.C. and D.C. service in two sizes, one about 9½ inch and the other 7½ inch diameters. The D.C. instruments work on the D'Arsonval principle, while the A.C. instruments work on the Thomson inclined coil principle, the appearance of these meters being as shown in Fig. 109.

D. C. Watt-hour Meters.—All G. E. direct-current switchboard watt-hour meters are essentially high torque devices. Friction is reduced to lowest value and ratio of torque to friction is maximum, insuring long life with continued accuracy. The design of the commutator and bearings is such that the possibilities of increased friction due to age and wear are minimized, hence the ratio of torque to friction increases, which is the real criterion of the accuracy of a meter, is very large.

Having no iron in armature or field circuits, no considerations of magnetic saturation are involved. Therefore, meters have straight-line characteristics even to point of physical destruction.

The armatures of the D.C. watt-hour meters are spherical and move in a circular field. This secures highest torque with lowest watt loss, the greatest possible number of magnetic lines being cut by the armatures. Their astatic arrangement minimizes effect of stray fields since any magnetic field tending to weaken the torque of one armature strengthens torque of the other.

A.C. Watt-hour Meters.—These meters for switchboard service are rectangular in shape and provided with metal cover or glass cover and arranged for single phase or polyphase service. These meters are provided with testing terminals that allow testing meters to be cut into the circuit or the meter winding isolated without interrupting the circuit or without going behind the switchboard. The corresponding house meters for single phase or polyphase service are provided with metal covers.

Round pattern curve drawing instruments are provided with electrical elements of the solenoid type, direct acting with gravity control. Charts are circular 8-inch diameter with a chart speed of one revolution in either 12 or 24 hours, but other speeds can be furnished.

Large graphic meters with a rectangular chart about 5 inches wide and a paper speed of 3 or 6 inches per hour can be supplied as ammeters, voltmeters, indicating wattmeters, power factor meters, frequency meters, etc.

BRISTOL, ESTERLINE, DUNCAN, SANGAMO METERS

A complete line of graphic instruments are made by the Bristol Company embracing the usual ammeters, voltmeters, and wattmeters, as well as recording thermometers, pressure gauges and other similar devices. The Esterline Company build graphic instruments of all kinds, while shunt type D.C. watt-hour meters are made by the Duncan and by the Sangamo companies. Space does not permit a description of them.

THE ROLLER SMITH COMPANY

The Roller Smith Company make indicating instruments in various sizes and shapes for D.C. and A.C. work to measure current, voltage, etc.

For direct-current work for batteries and automobile work, ammeters up to 100 amperes and voltmeters up to 150 volts are made with an over-all diameter of 3½ inches and body diameter of 2⅝ inches in either the protruding or flush styles of mountings. These instruments are of the permanent magnet moving coil type with light but rigid moving elements. These are known as "Junior Imps."

The 4-inch Imps are made as ammeters up to 200 amperes and as voltmeters up to 300 volts. These instruments are 4 inches in diameter of the moving coil type.

Junior and 4-inch Imp instruments are made as A.C. ammeters, voltmeters and single-phase wattmeters. The ammeters and voltmeters are of the electromagnetic type while the single-phase and D.C. wattmeters are of the electrodynamometer type. A very efficient air damping scheme is used.

The standard D.C. switchboard ammeters and voltmeters are made in 7½-inch and 9-inch round pattern protruding or flush type and illuminated dial. These meters can be furnished with the usual ranges and are all of the permanent magnet moving coil D'Arsonval type. Horizontal edgewise ammeters and voltmeters can also be furnished.

A.C. instruments can be supplied in the 7½-inch and 9-inch round patterns and illuminated dial types, the mechanism being the electromagnetic type air damped for the ammeters and voltmeters. Ammeters and voltmeters can also be supplied in the horizontal edgewise construction. Power factor meters, frequency meters, indicating wattmeters, synchronoscopes and ground detectors can also be furnished.

Recording Synchronoscope.—A recording device made by Schweitzer and Conrad, for attaching to a synchronoscope consists essentially of a paper holding and shifting device, and insulated ring in the synchronoscope dial and a spark coil or vibrator. A continuous ribbon of paper is fed from a metal spool on the left along guides and across the upper half of the synchronoscope dial to the spool on the right.

The dial plate of the ordinary synchronoscope is replaced by one of insulating material having a brass ring set in flush with its surface. The ring has a radius a little less than the length of the instrument pointer and is furnished with an insulated stud extending through the back of the indicator case. To the under side of the pointer and directly in line with the ring is attached a platinum point.

One of the leads from the spark-coil secondary is connected to the insulated stud, and the other to a stud screwed into the instrument case and therefore is in electrical connection with the pointer. The primary leads are connected to a direct-current source, such as the exciter or operating bus, through an auxiliary

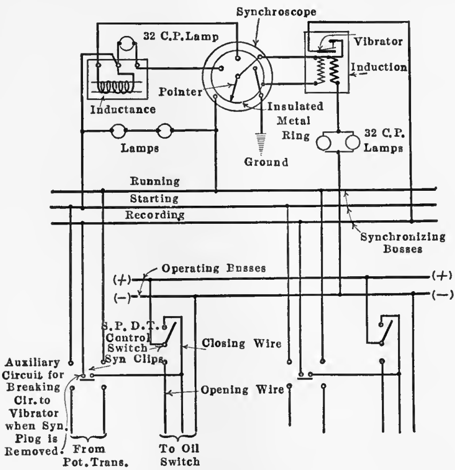


FIG. 110.—Connections of Schweitzer & Conrad record synchronoscope.

contact the location of which depends upon the scheme of control wiring. The purpose of the auxiliary contact is to close the circuit to the spark-coil primary simultaneously with the closing of the control switch and to keep it closed until opened by the operator.

The connections of this device are shown in Fig. 110. With the energizing of the spark coil at the time the control switch is closed, a succession of sparks jump from the insulated ring to the electrode on the pointer, puncturing the paper ribbon and so forming the record. For a perfect operation the record will be a very short row of quite large punctures. These will be all on one side of the synchronous position if the machine was running faster than the system frequency and all on the other side if slower.

WESTINGHOUSE INSTRUMENTS

As typical of a complete line of instruments, the various types made by the Westinghouse Electric & Manufacturing Company will be enumerated in considerable detail.

Small D.C.—For automobile service the type EI ammeters have 2-inch dials and $1\frac{1}{2}$-inch scales, while the type EW instruments are made as ammeters and voltmeters with 3-inch dials and $2\frac{3}{8}$-inch scales.

Type EI.—This instrument utilizes the polarized vane construction, comprising a moving soft-iron vane polarized by a stationary permanent magnet and deflected over its scale by the action of a stationary current coil. No springs or moving coils are used, thus resulting in great simplicity and ruggedness. The indications are made deadbeat by means of an efficient damper.

Type EW.—The instrument operates on the D'Arsonval principle, involving a permanent magnet and a moving coil, with spiral current-carrying springs, mounted in pivot and jewel bearings; the movement being rendered deadbeat by winding the moving coil on an aluminum damping frame.

Both types of these meters are mounted in open-faced circular pressed-metal cases arranged with a flange for flush mounting.

For use where small size is essential, the types BX, AW, EH and FW instrument designs are well adapted.

Type BX.—These instruments for direct current or alternating current of any frequency have 2-inch dials, 2-inch scales and they may be used for the measurement of small direct currents, such as the filament and plate currents of radio communication sets, or on farm-lighting or other small charging and lighting panels, or in dental, electro-medical, or other applications where space, economy and accuracy are essential.

Type BX instruments operate on the D'Arsonval principle. By combining the millivoltmeter with a noninductive heater and thermocouple it is made suitable for the measurement of high frequency alternating currents such as are encountered in radio communication. The same instrument may also be operated on alternating-current circuits of commercial frequency.

Type AW.—The type AW switchboard instruments for direct current are 3 inches in diameter with $2\frac{3}{8}$-inch scales and are especially suitable for use on small direct-current switchboard panels, such as battery charging, generator and control panels for marine, dental, telegraph, telephone and farm lighting equipments. The D'Arsonval type of movement is employed, using a case with a round open-face, glass cover, with rear mounting studs, stamped metal case and rim.

These instruments are guaranteed to be correct within 2 percent of full scale at all parts of the scale, and are 3⅛ inches in diameter over all and project 1⅞ inches from face of panel; studs suitable for panels up to ¾ inch thick.

Type FW.—The type FW switchboard instruments for direct current are 5 inches diameter with 4-inch scales and are similar in main features to the type AW.

Fig. 111.—Westinghouse D.C. instruments—comparison white and black dials.

Seven-inch Meters.—For most of the important switchboards built by the Westinghouse Company they utilize the 7-inch diameter meters known as type SL for D.C. service and SM, SI, or SD for A.C. These meters are made either with the usual white dials and black figures or with black dials having white figures. The relative legibility of the two different types of dials with the same illumination is shown in Fig. 111, where a lamp directly above and between two meters is provided with a half shade to throw the light directly on the dial of each meter.

D.C. INSTRUMENTS

Type SL.—These switchboard ammeters and voltmeters for direct current are intended for the most general switchboard applications, wherever highest grade instruments are required. Their cases are of soft iron, easily removed, the base remaining on the panel, and they are provided with covers of flat glass rendering the entire pointer visible; this makes it easy to take readings from a distance and from any angle. The scales are approximately 7 inches long and the meters operate on the D'Arsonval principle, but have a moving coil operating in a single air gap. The complete movement is readily removed for repairs. The single air gap construction makes it possible to remove the moving coil without first removing the pole pieces and without disturbing in any way the magnetic circuit.

Voltmeters.—The resistance of the voltmeters is approximately 50 ohms per volt up to 750 volts. For higher voltages the resistance is 100 ohms per volt. The accuracy is 1 percent of full scale at points between $\frac{1}{2}$ and $\frac{3}{4}$ scale, and average accuracy 2 percent of full scale at other points. These instruments have an over-all diameter $7\frac{7}{16}$ inches; depth from switchboard, 4 inches.

Ammeters.—With the exception of the self-contained styles, type SL ammeters operate from shunts and give full scale deflection with 50 millivolt drop at the terminals of the shunt.

Pyrometry millivoltmeters for use with thermo-electric couples can be adjusted for 20 to 100 millivolts, full scale. The current required at full scale is 0.01 amperes. The scale can be calibrated in millivolts or degrees.

For temperature indicators voltmeters arranged as resistance type temperature indicators, complete with coils or bulbs, can be furnished for reading the temperature of machinery, ovens, etc. The scale can be calibrated in volts or degrees.

Type SM.—The A.C. instruments, switchboard ammeters, voltmeters and wattmeters for alternating current have an over-all diameter of $7\frac{7}{16}$ inches; depth from switchboard 4 inches (the polyphase wattmeter requires hole $7\frac{1}{16}$ inches diameter through panel) with $14\frac{1}{2}$-inch scales.

Type SM instruments operate on the induction principle, with two A.C. fields so displaced that they produce a rotating magnetic field that causes an aluminum drum to tend to rotate. This tendency to rotation is opposed by a spiral spring.

The complete movement is readily removed for repairs. The moving element consists of a light drum and a pointer, both of aluminum, mounted on an aluminum shaft, with removable steel pivots.

The ammeters and voltmeters are guaranteed to be correct within 1 percent of full scale at all points of the scale; the wattmeters within 2 percent. The general appearance of this meter is shown in Fig. 112.

Type SI.—Other instruments of the induction type operating on a somewhat different principle are the type SI power factor meters, reactive factor meters and synchronoscopes, the power factor meter being shown in Fig. 113. These operate on the rotating field principle. In the rotating field produced by coils connected to the metered circuits there is pivoted a movable iron vane or armature, magnetized by a stationary coil the current for which is taken from a current transformer in one phase of the circuit. As the iron vane is attracted or repelled by the rotating field, it takes up a position where the zero of the rotating field occurs at the same instant as zero of its own field. Thus its position indicates the phase angle between the voltage and current of the circuit.

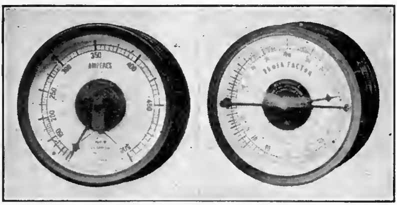


Fig. 112.—Westinghouse type S.M. A.C. ammeter.

Fig. 113.—Westinghouse power factor indicator.

In the 3-phase instrument the rotating field is produced by three voltage coils spaced 120 electrical degrees apart; and in the single-phase instrument by means of a split phase winding connected to the voltage circuit.

The instruments are enclosed in round, dust-proof cases. There are no movable coils or flexible connections and no springs are used to control the movement. The construction is, therefore, extremely simple and rugged. External fields can not influence the readings.

Synchronoscope.—The type SI synchronoscope indicates by means of a pointer, which assumes at every instant a position corresponding to the phase angle between the E.M.Fs. of the bus bars and the incoming machine. It gives exact indications and pointer is continuously visible during both the dark and the light periods of the synchronizing lamps.

The principle of operation is a rotating field produced by current from the bus bars passing through a split phase winding and two angularly placed coils. In this rotating field is a movable iron vane, or armature, magnetized by a stationary coil connected across the incoming machine. The iron vane takes a position where the zero of the rotating field occurs at the same instant as the zero of the stationary field. Thus its position at every instant indicates the phase angle between the voltage of the incoming machine and that of the bus bars. As this angle changes, due to difference in frequency, the iron vane with the pointer attached to it rotates, and when synchronism is reached it remains stationary.

Frequency Meter.—Still another induction type instrument is the type SD switchboard frequency meter. The instrument, which operates on the induction principle, consists of two voltmeter electromagnets acting in opposition on a disk attached to the pointer shaft. One of the magnets is in series with a reactor and the other with a resistor, so that any change in the frequency will unbalance the forces acting on the shaft and cause the pointer to assume a new position where the forces are again balanced. The aluminum disk, acted upon by the magnets, is so arranged that when the shaft turns in one direction the torque of the magnet tending to rotate it decreases, while the torque of the other magnet increases. The pointer, therefore, comes to rest where the torques of the two magnets are equal. This arrangement insures freedom from error due to varying voltage.

Illuminated Dials.—Where illuminated dial instruments are wanted they can be supplied for either D.C. or A.C. service. The direct-current instruments operate on the D'Arsonval principle and alternating-current instruments on the induction principle. The movements are similar to these of the corresponding round type instruments. The scales are 15¼ inches long, and are made of translucent material, illuminated from the rear by two 110-volt 6-candlepower tubular lamps.

The D.C. voltmeters and ammeters are guaranteed correct within 1 percent of full scale at all points. The A.C. voltmeters are guaranteed to be correct within 1½ percent of full scale at all points; ammeters 2 percent at all points.

These instruments have the following dimensions: Over-all height, 12⅛ inches; over-all width, 15¾ inches; depth 3 to 3½ inches; mounting screws suitable for switchboards up to 2 inches thick.

Glow Meters.—The electro-static glow meter is a vacuum tube type of electrostatic potential indicator that may be used for indication of potential on the line, as a ground detector connected as shown in Fig. 114 or as an electro-static synchronism indicator connected as shown in Fig. 115.

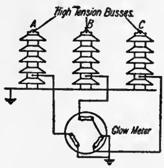


Fig. 114.—Glow meter connected as ground detector.

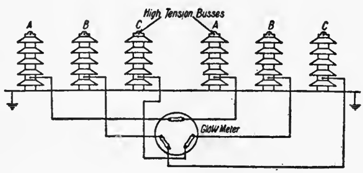


Fig. 115.—Glow meter connected as synchronoscope.

The indicating device consists of three small bulbs filled with a rare gas which gives out a vivid orange-red glow on an extremely small static discharge, such as can be obtained over one section of a multi-section line insulator. The base of the instrument is of micarta and the bulbs are mounted between spring clips and are separated from each other by micarta tubing which forms barriers for the light from the individual bulbs.

This instrument utilizes the electrostatic discharge of one section of an insulator column. When used as a ground detector one bulb is in parallel with the bottom section of each of the three insulator columns.

Static Synchronizer.—When used for synchronizing, the phase connections through the top lamps are so made that the lamp will be out at synchronism. The phases of the two lower lamps are crossed so that they glow at synchronism. When out of phase 60 degrees, all three lamps have about half voltage impressed on them and glow with the same brilliancy; when out of phase 120 degrees, one of the bottom lamps is out and the other bottom lamp and the top one are glowing. If the two circuits are out of synchronism there will be an apparent rotation of the light in such a direction as to show whether the incoming line is fast or slow.

Watt-hour Meters.—The type OA watt-hour meters shown in Fig. 116 operate on the induction principle. The torque that rotates the disk is proportional to the product of voltage, current and power factor of the circuit, and is counter balanced by a retarding force exactly proportional to the speed. The speed of rotation is, therefore, proportional to the power in the circuit.

Polyphase type OA meters are in reality two single phase meter elements supported on one mounting frame, both moving elements being mounted on a common shaft and driving a common register.

When properly connected, these meters indicate the true power in a 2-phase 3-wire or 4-wire, or a 3-phase 3-wire circuit, regardless of the power factor or the degree of unbalance between phases.

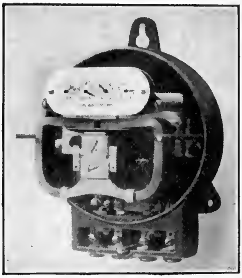


Fig. 116.—Westinghouse single-phase watthour-meter—cover removed.

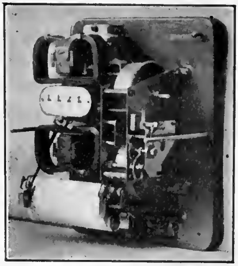


Fig. 117.—Westinghouse recording demand watthour-meter.

Extra terminals are provided on the front of the meter under the cover to facilitate checking the meter while in service. These terminals are so arranged and connected by test-links that the test meter can be inserted in the circuit from the front of the switchboard, for testing the switchboard meter, without opening the current transformer circuits. By these terminals and links, the switchboard-meter elements can likewise be disconnected from the transformer circuits, the current transformers being short-circuited, and connected to a test load and portable standard watt-hour meter.

Demand Meter.—The type RA recording demand watt-hour meter shown in Fig. 117 in one unit measures both the kilowatt hours consumed and the integrated demand. It indicates on a four-counter dial the total kilowatt hours consumed and records in a permanent form the integrated demand over successive predetermined time intervals.

It is applicable for determining the demand of power installations where a permanent record of the demand, involving the time and length of occurrences, is wanted.

The type RA recording demand watt-hour meter consists of a watt-hour meter with the usual four-counter register and, in addition, the mechanism for obtaining a graphic record of the demand. The time interval of the meter and the advance of the record paper are controlled by a hand-wound clock mechanism.

Under load, the gear train of the watt-hour meter advances the counters in the regular manner. At the same time the gear train causes the ink-carrying pen to advance across the record paper in proportion to the energy registered. At the end of a predetermined time interval a stud on the reset wheel releases the pen gear from mesh with the gear train and a balancing weight returns the pen to zero where it is again meshed with the gear train to repeat its advance during the next time interval.

Just before the pen gear is released, the record paper is advanced a sixteenth inch by the operating spring so that the pen makes a distinct and readily observed record of the maximum pen travel, showing both the amount of integrated demand and, by the time calibration printed on the record paper, the time of its occurrence.

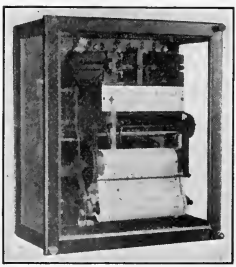


Fig. 118.—Westinghouse graphic recording instruments.

The reset wheel, which makes one complete revolution per hour, is arranged for the insertion of four studs. When all four studs are used, the meter has a 15-minute time interval on the integrated demand. With two studs in place, arranged 180 degrees apart, the meter has a 30-minute time interval; and with only one stud, a 60-minute interval.

Graphic Meters.—The type M Switchboard graphic instruments for alternating and direct-current circuits shown in Fig. 118 make an accurate and permanent record of the electrical quantities involved in power house operation. Records of kilowatt output are especially important. The load wave indicated by this instrument furnishes a basis for rates to prospective customers whose probable demands for electric power during different hours of the day can be estimated.

Relay Principle.—All instruments operate on the relay principle, the measuring element actuating only contacts and not moving the pen directly. In turn, these contacts energize a device arranged to move the pen. The use of resistances prevents harmful sparking at the contacts, which are made of special alloy.

The approximate dimensions of all except direct-current wattmeters are: over-all width 13¼ inches, over-all length 16½ inches, over-all depth 9⁵⁄₁₆ inches.

The record is made by a pen moving in a straight horizontal line at right angles to the motion of the paper, giving a scale having rectangular co-ordinates.

The motion of the pen and consequently the sensitiveness of the instrument may be regulated easily, and the record made either to show slight variations in the circuit or to slur over these irregularities and form a more even line. The pen can be made to travel full scale in any time from 1 to 30 seconds. This motion is absolutely dead beat so that the pen will not "overshoot."

Paper.—The record paper is supplied in a long roll providing continuous records for any desired period. It is legibly printed in black and is inexpensive. The width is approximately 6¾ inches, the scale being 5¼ inches. Standard rolls are for two month's service at a speed of 2 inches per hour. The standard paper speeds are 1, 2, 4, or 8 inches per hour. Each instrument has a paper collecting roll of 124 feet capacity.

The clock, which turns the paper rolls, is of the electric self-winding type and operates from the control circuit at the end of each 2-inch period.

Paper Speed.—If an instrument is desired the speed of which can be adjusted from 8 to 4 or 2 inches per hour, a clock suitable for this purpose can be provided with extra sets of gears.

In direct-current ammeters and wattmeters and in power factor meters, the pen is operated by solenoids energized through the relay contacts. In alternating current-direct-current voltmeters, alternating-current ammeters and wattmeters, and frequency meters, the pen is operated by a small motor similarly energized through the relay contacts.

Ammeters, voltmeters, wattmeters, and frequency meters are guaranteed correct within 1 percent of full scale at all points.

Meter Elements.—The measuring elements of alternating-current and direct-current voltmeters, alternating-current ammeters and alternating-current and direct-current wattmeters are of the Kelvin-balance type. They are independent of variations in frequency, external fields, temperature, power factor, or wave form. Polyphase wattmeters are correct with any degree of unbalancing of phases. Direct-current ammeters are of the permanent magnet type with moving coils, and operate from shunts.

Direct-current wattmeters are similar to the alternating-current wattmeters except that the series coils are designed to carry the total current.

Totalizing Graphic.—Type M totalizing graphic wattmeter is used for measuring the total power in a group of 2 to 12 independent circuits.

It is possible to record on this instrument the total power in several circuits not in synchronism or of different characteristics such as frequency, transformer ratio, voltage, etc. These instruments can be made for any capacity and frequency and can be used with instrument transformers in service, even though of different ratios. The measuring elements are all mechanically connected to one set of contacts, so that it is the total pull of all the elements that closes and opens the contacts. The control element is supplied for operation by either direct current or by alternating current, as ordered.

Type U Graphics.—These graphic ammeters and voltmeters are intended for purposes where graphic instruments that are easily operated, light in weight, comparatively low in price, and reasonably accurate are required. The instrument consists of a solenoid and core acting on an arm that carries the recording pen, and a continuous strip of paper moved uniformly by a clock mechanism. To overcome the slight friction of the pen on the paper, the solenoid is made powerful in its action. Its action is controlled by a heavy spring, which minimizes inaccuracies due to slight errors in leveling. The energy consumed by the voltmeter, including its external resistor, is 25 watts. The energy consumed by the ammeter is 7 watts, thus adapting it for use with ordinary current transformer for currents higher than the current rating of the instrument. On direct current the type

U voltmeters have an accuracy of 2 percent and ammeters 3 percent, with somewhat greater accuracy on alternating current. Temperature errors, and errors due to ordinary frequency changes are negligible.

Temperature Indicators.—These devices for switchboard mounting are desirable, especially in large capacity generators, in order to know what are the maximum temperatures in the machine so that the load may be controlled in accordance with the safe temperature limits of the insulation.

Methods.—Three general methods of temperature measurements may be used: by thermometer, by measuring increase in the resistance of the windings, and by embedded temperature detectors. With the first of these, surface temperatures of stationary parts only can be observed. The second method gives only average temperatures of the winding and does not give temperatures of hot spots. It is, therefore, upon the third named method that the greatest dependence can be placed.

There are two forms of embedded detectors for temperature measurement: exploring coils, and thermocouples.

Exploring Coils.—Outfits for use with embedded exploring coils give a direct and continuous indication of temperature. A separate source of direct current of constant voltage must be provided.

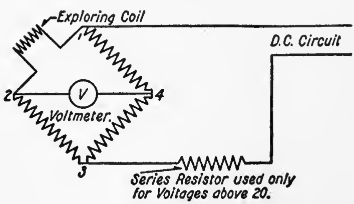


Fig. 119.—Temperature indicating diagram.

The Wheatstone bridge principle is used. The exploring coil is a resistor, the resistance of which varies with the temperature of the mass surrounding it, and forms the fourth arm of the bridge. The values of the other three resistances of the bridge are such that when the temperature of the exploring coil has reached some predetermined value the bridge is in balance and there is no difference in voltage between points 2 and 4, Fig. 119. With the exploring coil at any other temperature, there will be a difference in voltage indicated on the voltmeter which is calibrated in degrees. The four arms of the bridge are made equal at the temperature for which greatest accuracy is desired, and at this temperature the indications will be independent of applied control-circuit voltage. The standard temperature is 100 degrees Centigrade, but any other temperature may be chosen for balance. The instrument can be calibrated for any temperature that the exploring coils can withstand.

The exploring coil is made up of a large number of turns of copper wire wound on a strip of mica. The finished coil is about 5 inches long and $\frac{1}{16}$ inch thick and at normal temperature has a resistance of approximately 30 ohms.

The bridge resistors are generally mounted in a bridge box back of the switchboard panel, and any source of direct current of constant voltage will serve.

Thermocouples.—Outfits for use with embedded thermocouples balance the E.M.F. of the test couple against that of another couple at known temperature; it thus avoids all errors due to variation in leads, etc., and as it indicates on the "null" or zero-reading principle, very accurate readings can be obtained. Danger of short circuit or open circuit when placed in machine is a minimum.

One thermocouple is embedded in the mass of which the temperature is to be measured and the other, the "cold" couple, located where its temperature can be easily recorded on a thermometer. An instrument can then be so connected that it will show the difference in voltage between the two couples and therefore the temperature can be easily determined.

Calibrations.—The instrument is calibrated to read directly the temperature of the test couple that is made by welding copper and "advance" (nickel-copper) alloy ribbons together. These ribbons are ordinarily 0.005 inch thick, 0.25 inch wide and of any desired length. The couple is insulated with mica and micarta paper to withstand a temperature of at least 150 degrees Centigrade. An inherent characteristic of this couple is that its difference in potential is 42 microvolts per degree Centigrade difference between the two couples.

The Westinghouse type DT temperature indicator combines in one case all necessary parts except the test couple. It operates on the "potentiometer principle." The instrument case contains the "cold" couple which is in contact with the bulb of a mercury thermometer, by which the temperature of the "cold" couple is observed.

A dry cell supplies current to a resistance wire equipped with two sliding contacts. The drop of potential between these contacts is proportional to the current in the wire and to the distance between them. Two pointers which move with the contacts indicate the positions of the two contacts. The scale is calibrated in millivolts and degrees; divisions on the millivolt scale are of equal width; divisions on the temperature scale are spaced according to the E.M.F. law of the couple. A rheostat in the battery circuit is used for adjusting the current exactly to the value that will cause a drop of E.M.F. per degree on the temperature scale equal to the thermo E.M.F. per degree in the couples. Leads from the thermocouple connect through a sensitive galvanometer to the slide wire contacts of corresponding polarity. If the E.M.F. between the contacts is equal to the thermo E.M.F., there will be no deflection of the galvanometer. If higher or lower, there will be a deflection of the galvanometer in one or the other direction. By changing the distance between contacts, using the galvanometer as a guide, the position at which the slide E.M.F. balances the thermo E.M.F. is easily located.

In practice, the lower pointer is set at the position on the scale corresponding with the temperature of the "cold" couple and the upper pointer is moved until a balance is obtained as described. Actual temperature of "hot" couple can then be read directly on the scale.

One galvanometer serves both for measuring the current in the slide wire, in which case it is connected in multiple with a shunt, and for indicating balance when it is connected directly in series with the couple.

Leads.—In ordinary practice, individual copper wire leads are used to connect each individual couple through a dial switch on the switchboard to the instrument and a common advance alloy lead connects all the couples to the instrument. This side of the circuit is usually grounded in order that no voltage may be carried to the switchboard by failure of the armature coil insulation to the couple, which would allow generator potential on the circuit; also in order that any static disturbance may not affect the accuracy of the instrument.

It is usual to install six thermocouples in each generator. The leads from these are then brought out to a terminal board on the generator and from there to the switchboard. By installing a dial switch on the switchboard, connection can be made readily from the instrument to any one of the couples.

WESTON INSTRUMENTS

The Weston Electrical Instrument Company makes a very complete line of instruments for switchboard service as well as for laboratory and general testing purposes.

Types.—For D.C. service, ammeters and voltmeters are available in either round cases, illuminated dial fan-shaped cases or vertical edgewise cases, to suit different conditions. The higher grade instruments are all made of the pivoted movable coil permanent magnet type usually known as the "D'Arsonval" type, with the ammeters operated from shunts with a drop of 50 millivolts.

FIG. 120.—Flush mounting round pattern Weston D.C. meter.

Round Pattern.—The round pattern meters are made with binding posts on the front of the meter or with rear connected studs or of the flush type, the latter being shown in Fig. 120. The ammeters up to 75 amperes are self-contained with the shunt forming an integral part of the meter. For higher capacities the shunt is separate. The current at full scale is about 0.04 amperes at 0.05 volts so that the energy taken by the meter is only 0.002 watts. Based on a full load of 1000 amperes the loss in the shunt with 0.05 volts drop is 50 watts with proportionate losses at other currents. The round pattern meters, model 57, have an external diameter of 9.562 inches, a scale length of 6½ inches. A smaller type of round pattern meter known as the model 24 has an external diameter of 7¼ inches, a scale length of 5$\frac{1}{16}$ inches and has an accuracy of 1 percent.

Eclipse Meters.—A cheaper line of round meters known as the "Eclipse" are made on the soft-iron or electromagnetic principle. The ammeters are connected directly in the circuit and are built in capacities up to 500 amperes. These meters are made in two diameters, the same as for the previous types.

Illuminated Dial.—For large D.C. switchboards illuminated dial meters can be supplied either for attaching by means of brackets to the front of the switchboard or of the flush type countersunk in the switchboard. The scale length of these meters is 11.8 inches and the scale of translucent glass is illuminated from the rear. The voltmeters can be supplied as differential meters for paralleling purposes or with zero center where desired. These meters have a width of 14.62 inches and height of 13.20 inches for the normal type, but a smaller design is available, $9\frac{15}{16}$ inches wide, $8\frac{3}{4}$ inches high. For special service instruments are available with a scale length of 28.09 inches, width 27.375 inches, height 19.50 inches, or with a scale length of 37.65 inches, a width of 38.75 inches and a height of 29.25 inches.

Fig. 121.—Vertical edgewise Weston meter.

Edgewise.—Where it is desired to place instruments in an elevated position or very close together, the vertical edgewise meters shown in Fig. 121 can be furnished for assembling in carrying frames accommodating from 2 to 6 meters. These meters are so arranged that they can be tilted forward at any angle.

A.C. Meters.—A complete line of A.C. switchboard instruments is also built by the Weston Company. For ammeters and voltmeters the soft-iron or electromagnetic construction is adopted and the meters are made of the round type either $9\frac{5}{8}$ inches or $7\frac{1}{4}$ inches diameter and have scales that are fairly uniform.

Wattmeters.—The wattmeters are built on the electrodynamometer principle, as are the synchronoscope and power factor meter. The fixed winding of a single-phase wattmeter is made up of two coils which act together to produce the field of the wattmeter, these being fed from a series transformer. The movable coil placed inside the fixed coils is connected in series with a resistor in a voltage circuit. The general appearance of a single-phase wattmeter is shown in Fig. 122. As the current in the series (stationary) coils increases the movable (potential) coil tends to turn so that the fields of the two elements will coincide. This tendency is resisted by a spring but the movable coil in turning causes the pointer to pass over the scale until a point is reached when the torque of the coils is just equal to the restraining torque of the spring. The polyphase wattmeter has two of the single-phase meter elements so located in tandem as to act on the same shaft.

The field coils of the synchronoscope are very similar to those of the wattmeter, except that they are wound with much smaller wire as they are essentially potential coils in place of current coils. The field coils of the power factor meter are similarly placed but made in an elongated form.

FIG. 122.—Weston indicating wattmeter.

In all of these instruments the pointer is made in the form of a triangular truss with tubular members, making a very stiff construction with very small weight. An effective form of air damper is used, made with very thin metal stiffened with ribs, the whole damper being placed in a damper box where the air leakage is reduced to a minimum, increasing greatly the amount of damping while keeping down the weight and the moment of inertia.

Synchronoscope.—The Weston synchronoscope has a switchboard electrodynamometer movement, mounted with the pointer behind a translucent glass scale and illuminated by a synchronizing lamp connected to synchronize light. The fixed coil is connected across the line through a resistor and the movable coil is connected through a condenser across the incoming machine. The pointer stands normally in the middle of the scale. The mechanical construction of this instrument is similar to that of the Weston single-phase wattmeter, except that both the fixed and movable coils are wound with fine wire.

Since the lamp is dark when the E.M.Fs. are in phase opposition, and light when they are in phase coincidence and have the same frequency, the pointer will be seen at rest in the middle of the scale when perfect synchronism is attained.

When the E.M.Fs. are not exactly in phase or in phase opposition, there will be torque tending to turn the movable coil, the value of the torque increasing with the phase displacement.

The direction of the torque depends upon the relative directions of the currents in the coils; that is, the direction of deflection indicates whether one lags or leads with respect to the other.

If the two machines are not running at the same frequency, the phase displacement will continuously shift from phase coincidence through complete cylces of 360 time-degrees, and with it the torque will vary continuously from zero to plus maximum, back through zero to minus maximum, etc., thus causing the pointer to swing back and forth over the scale. Each swing denotes a shift in phase angle from quadrature plus or minus to quadrature minus or plus, and, therefore, it will coincide with a period of light or darkness, and the pointer will be seen only during every other swing; that is, it will appear to rotate in one direction.

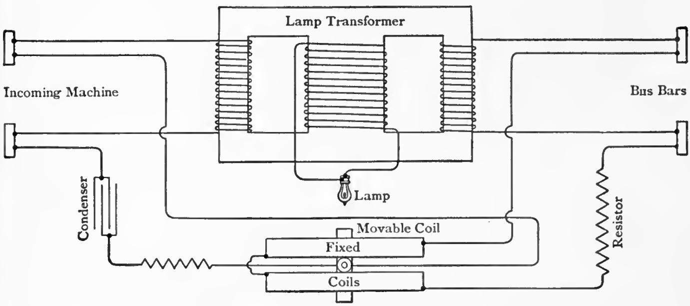


Fig. 123.—Diagram of connections. Weston synchronoscope.

The direction of apparent rotation indicates whether the incoming machine is fast or slow and the speed of rotation is a measure of the amount by which the frequencies differ. If the machines have the same frequency but are not in phase coincidence, the pointer will come to rest at some point at one side or the other of the middle of the scale.

The connections of the various operating parts of the synchronoscope are shown schematically in Fig. 123.

Power Factor Meter.—The powerfactor meter is a special form of electrodynamometer. Its movable system consists of two circular coils arranged on the same staff and in planes at right angles to each other. The movable coils of the power factor meter are practically identical in magnetic strength when traversed by the same current, and are accurately and permanently located in planes at right angles to each other. The coils are wound by machine and interlaced layer for layer at diametral crossing points. The completed coil is then treated with a special cement which gives it exceedingly great rigidity, and thus assures a permanent relative location of the coils. The general construction is quite similar to that of the single phase wattmeter.

On polyphase systems, the movable coils are connected across leads in which the E.M.F. differs in time-phase, while on single-phase circuits a phase-splitting device is used. When the current in one of the movable coils is in time-phase with that in the fixed coil it will place itself parallel with the fixed coil. If the current in the fixed coil reaches its maximum at some time intermediate between the time of maximum current in either of the other coils, the movable coils will take a position such that the resultant maximum field, which is in time-phase with the fixed field, due to the fixed coil will coincide with the fixed field.

Since the fixed field is in time-phase with the load current, and the field of one of the movable coils is in time-phase with the E.M.F. between leads, the space position of the resultant field of the movable coils, which is in phase with the fixed field, will vary with the phase angle between E.M.F. and current; that is, the deflection of the movable system is a measure of phase angle or power factor.

Frequency Meter.—This meter indicates accurately the instantaneous value of the frequency of the system to which it is connected. Its movement is of the soft-iron type with two fixed coils, each made up of two sections. They are wound flat and one is slipped inside the other and at right angles to it. The movable system consists of a staff carrying a damper, an iron needle and a pointer; it is mounted in highly polished sapphire jewel bearings. There are no springs or other connections to the movable system, therefore, it is perfectly free to rotate.

The shape of the fixed coil is such as to establish with minimum material a strong field of uniform density, such as is necessary to the production of uniform scale. The needle is extremely thin and is made of a special alloy having a low hysteretic constant.

The coils are connected in series across the line, with a reactor in series with one and a resistor in series with the other. A resistor is connected in parallel with one coil and the reactor, and a reactor is connected in parallel with the other coil and the resistor; then the whole combination is connected in series with a reactor, the purpose of which is to damp out the higher harmonics. The circuits form a Wheatstone bridge, which is balanced at normal frequency. An increase in frequency will increase the reactance of the reactors and thus upset the balance of the bridge, allowing more current through one coil and less through the other. Therefore, every change in frequency is accompanied by a corresponding shifting of the space position of the resultant field, which is indicated by the pointer.

These A.C. meters are usually made about $9\frac{5}{8}$ inches in diameter but the ammeters and voltmeters can also be furnished $7\frac{1}{4}$ inch diameter.

CHAPTER VII

INSTRUMENT TRANSFORMERS

Functions.—Owing to the small amount of power required for the operation of A.C. switchboard instruments, circuit-breaker trip coils and relays, and the difficulty of insulating them for high voltages or making them with current coils of large capacity, it is customary to furnish voltage transformers for pressures over 600 volts and to use current transformers where the current exceeds a certain value or the voltage is above 2400 volts. For the purpose of interchangeability most instruments and relays used with transformers are made with voltage coils to be operated at a maximum of 150 volts and current coils for a maximum of 5 amperes.

Voltage.—The voltage transformers are made of the dry type for pressures of 200 to 6000 volts, while oil insulated voltage transformers are made for pressures of 200 to 60,000 volts or higher. Where these voltage transformers are used with from one to three instruments they are usually compensated to give accurate transformation ratios at an output of 15 volt amperes, while with a greater number of instruments or when used with a regulator or similar device they are compensated to give a correct ratio at 100 or 200-volt ampere outputs.

Currents.—Current transformers are made in various designs, either dry or oil immersed, depending on the voltage. As a rule the current transformer steps down from a comparatively large current to a smaller one and the primary consists of a few turns connected directly in the main circuit. For very accurate work the number of ampere-turns should be at least 600 but where great accuracy is not required and the secondary load is small the number of primary ampere-turns can be greatly reduced. For currents of 600 amperes or more, transformers with accurate current ratio and very small "phase displacement error" can be made without any primary winding and arranged to slip over the cable, switch stud, bus bar strap or similar connection, which then forms the primary. For use with relays or with ammeters calibrated specially current transformers of this type can be made for ratios down to 100–5, or even smaller in certain cases.

Oil Immersed.—For high voltage service oil immersed current transformers are used and where it is desirable to have two different current ratios for the operation of various instruments and relays it is possible to build transformers with one primary coil, two iron circuits and two secondary coils to give the two different ratios desired. Dry type transformers are also built of this "double secondary" construction.

By the use of current and potential transformers low voltage circuits are obtained with characteristics in practical agreement with the high voltage circuit. Current transformers are extensively used to obviate the necessity of carrying large or high voltage conductors to instruments and protective devices.

Purpose.—An instrument transformer is a device suitable for use with measuring instruments in which the conditions of current, potential and phase in the primary or high voltage circuit are represented with acceptable accuracy in the secondary or low voltage circuit.

While accuracy is of vital importance, it is absolutely essential in current transformers that their construction be such as to withstand momentarily short-circuit currents many times their rated carrying capacity without injury. Furthermore, it is of great importance that the design afford a high degree of insulation. Unusual care has been exercised in the design of transformers to provide a high factor of safety.

Load.—Tripping coils of most protective devices usually impose a heavy "burden" upon current transformers. Where extreme accuracy is required, it is recommended that separate instrument transformers be used to supply energy to instruments or meters, and that tripping transformers be used in connection with trip coils of protective devices.

Precautions.—Current transformers should not be mounted where they will be exposed to unduly high temperatures, oil drippings, moisture, etc., and care should be taken that the primary terminals are properly insulated.

In mounting current and potential transformers, sufficient distance should be provided between terminals of adjacent transformers and between terminal and ground, to prevent flash-over due to momentary voltage surges. The transformer frame and secondary windings should be thoroughly grounded to eliminate electrostatic charges and afford protection to attendants. Contact to ground should be thoroughly inspected before working on the circuit.

The secondary circuit of current transformers should not be opened with current in the primary, owing to the high voltage momentarily induced when the circuit is opened. It is well always to short-circuit the secondary windings of current transformers before disconnecting instruments, meters, or tripping coils.

Transformers should be handled with care to prevent mechanical injury or possible weakning of insulation.

Makers.—Nearly all manufacturers of instruments and oil circuit breakers make current and potential transformers for use with them. Those of the Condit Company and the Westinghouse Company have been selected for description as being fairly typical.

Types.—The current transformers of the Condit Electric Manufacturing Company, are built in two sets of types, the 'B' for circuit-breaker tripping, and the 'S' intended for use with meters as well as trip coils.

Fig. 124.—Condit Electric & Mfg. Co. current transformer type B-6.

Type B-6.—This type shown in Fig. 124 is intended for primary windings from 5 to 200 amperes at voltages not exceeding 7500 for either 25 cycles or 60, to carry a load of one ammeter and one indicating wattmeter for the best efficiency and a maximum load of one ammeter and one circuit-breaker coil. It has a capacity of about 50 volt amperes. It is made with a wound primary containing the proper number of turns, and it is designed to stand the electromagnetic and thermal effects resulting from sustained short circuits.

Type B-4.—The type B-4, Fig. 125, for currents from 300 to 600 amperes at voltages not exceeding 7500, is intended for slipping over a cable or stud and is provided with a circular opening 2 inches in diameter. It has an output of 40 volt amperes with 5 amperes in the secondary at 60 cycles and 20 at 25 cycles.

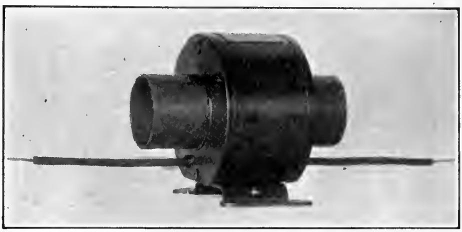


FIG. 125.—Condit Elec. & Mfg. Co. current transformer type "B-4."

Type B-5.—This is made for currents from 600 to 1200 at voltages not exceeding 4500 and is intended for slipping over rectangular bars and has an opening of $2\frac{9}{16} \times 4\frac{5}{16}$ inches. It has same output as the type B-4 and same general appearance except provided with a rectangular opening in place of circular.

Type B-8.—This is built for currents from 1500 to 3000 and is intended for slipping over rectangular bus bars or multiple cables for voltages not exceeding 4500. It has an output of 50 volt amperes at 60 cycles and 25 at 25 cycles. It has an opening $2\frac{3}{8} \times 4\frac{1}{8}$ inches.

These larger capacity transformers are designed primarily for operating circuit-breaker trip coils, but they may be used to operate indicating meters in conjunction with trip coils and will afford the usual accuracy required of indicating meters for switchboard service.

Type B-7.—These current transformers are built for currents from 300 to 500 amperes for voltages up to 15,000 and are intended to withstand heavy short-circuit stresses without distortion. It has the same output as the B-4. The B-9 and B-11 transformers have current ratings from 5 to 300 amperes for voltages up to 25,000 and 50,000 volts respectively for indoor service and the B-13 and B-14 are the corresponding outdoor transformers.

Type SI & SC.—The type SI current transformers are built double ratio for currents from 5 to 800 amperes and voltages up to 15,000 for circuit-breaker trip coils and indicating meters. It can readily be used as a differential transformer, and is built to withstand short-circuit stresses on large systems. It has an output of 60 volt amperes at 60 cycles and 30 at 25 cycles. The type SC is designed primarily for use with instruments where a high degree of accuracy is desired. It resembles the type SI in its general features.

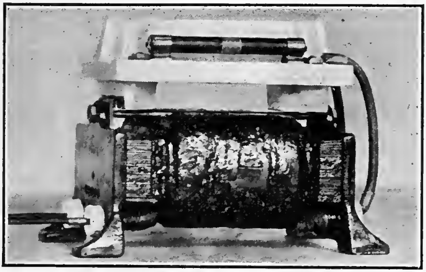


Fig. 126.—Condit Electric Mfg. Co., potential transformer, type "W."

Voltage Transformer.—The type W transformer, Fig. 126, is dry insulated, thoroughly impregnated, and exceptional care has been exercised to provide a high factor of insulation. All transformers have one primary and one secondary lead properly marked to indicate the polarity. The windings are so related that the instantaneous "ingoing current" of the marked high voltage or primary lead corresponds to the "outgoing current" of the marked low voltage or secondary lead. The transformer is so constructed that a minimum space is required for its installation. For pressures of 2500 volts or less, the cut-out base may be furnished as an integral part of the transformer and makes a very compact and neat arrangement. On pressures in excess of 2500 volts the fuse base must be separately mounted. Oil insulated transformers are supplied for pressures in excess of 5500 volts.

GENERAL ELECTRIC TRANSFORMERS

The General Electric Company have a very complete line of current and potential transformers for all classes of service practically paralleling the line of Westinghouse transformers whose description follows.

WESTINGHOUSE TRANSFORMERS

Type K.—Westinghouse current transformers, type A (dry type) indoor, are designed for normal voltage of 4600 2-wire, 1150 3-wire, test voltage for one minute of 14,000 2-wire, 5000 3-wire; for 25 to 133 cycle circuits; capacity 25 volt amperes, compensated for 12½ volt amperes.

Two-wire.—The type K 2-wire transformers comprise a line of low priced transformers of good accuracy, available over a large range of application. This type is suitable for ammeter, wattmeter, or watt-hour meter use, but may be used also for operating relays and circuit-breaker trip coils where the load at 4 amperes does not exceed 25 volt amperes at 25 cycles or 65 volt amperes at 60 cycles. They should not be used with relays where the circuit-breaker trip coil is connected in series with the relay.

Three-wire Type K.—Designed for use with watt-hour meters on 3-wire distribution systems. The primary consists of two separate windings, one of which is connected in each outside wire of the 3-wire system, and the secondary winding is connected to the watt-hour meter. When so connected, the watt-hour meter measures the total output of the system. The ampere rating refers to the current in the outside wires.

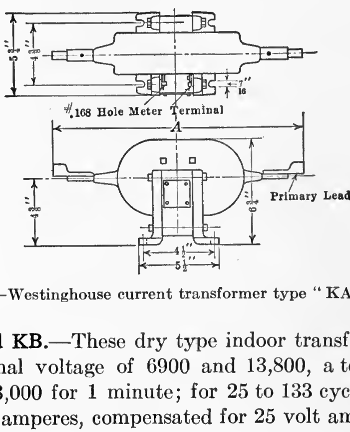


Fig. 127.—Westinghouse current transformer type "KA."

Types KA and KB.—These dry type indoor transformers are built for a normal voltage of 6900 and 13,800, a test voltage of 16,500 and 33,000 for 1 minute; for 25 to 133 cycle circuits; capacity 50 volt amperes, compensated for 25 volt amperes. A high degree of accuracy in the ratio of primary to secondary current and a minimum phase displacement error are obtained in these transformers. This type is for indoor use in all cases where highest accuracy is required.

As shown in Fig. 127, the transformers are arranged with the primary leads on the opposite ends of the coils, an arrangement well adapted for switchboard use. Lugs are provided for mounting purposes.

Type KC.—These dry type indoor transformers are built for a normal voltage of 23,000, test voltage of 52,200 for 1 minute; for 25 to 133 cycle circuits; capacity 50 volt amperes, compensated for 25 volt amperes. They are mounted in cast-iron end caps which are filled with insulating compound. This construction insures ample insulation between the high voltage winding and the secondary winding or the core.

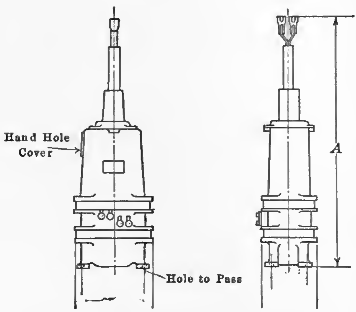


Fig. 128.—Westinghouse current transformer type "KC" double secondary.

Double secondary type KC transformers shown in Fig. 128 are similar in construction and voltage rating to the type KC, but have two independent secondary windings, each compensated for 25 volt amperes. One of these transformers, therefore, takes the place of two ordinary transformers on the same circuit.

Relay Transformers.—Type KR (dry type) indoor transformers for operating relays and circuit-breaker trip coils have a maximum voltage of 6900, test voltage, 16,500 for 1 minute, for 25 to 133 cycle circuits. This line of transformers in capacities 5 to 200 amperes inclusive is supplementary, for circuit-breaker use, to the through type FR transformers listed in capacities up to 500 amperes. These transformers have sufficient capacity to operate relays or trip coils and will have an error in ratio not exceeding about 10 per cent. where the load at 4 amperes does not exceed 25 volt amperes at 25 cycles or 65 volt amperes at

60 cycles. They should not be used with relays where the circuit-breaker trip coil is in series with the relay.

These transformers are for use only with relays, or circuit-breaker trip coils. They have sufficient capacity for operating circuit breakers within the limits of ordinary accuracy demanded in such service but should not be used for connection to measuring instruments. The general type of construction is similar to type KA transformers, except that these are much smaller.

The through-type FR (dry type) indoor transformers for operating relays and circuit-breaker trip coils, for 25 to 133 cycle circuits are similar to types FS and FB; but in the capacities covered by this line, 100 to 500 amperes inclusive, a through-type transformer cannot be made of sufficient accuracy for ordinary use in connection with measuring instruments. This line of transformers is, therefore, primarily adapted for circuit-breaker tripping, either through relays or by direct connection to the breaker.

Special Calibration.—In order to obtain the advantage of a through-type transformer of low current rating for instrument service, these transformers may be so used where it is possible to calibrate the instrument with the transformer. This application can only be made in the case of ammeters, and requires the use of a calibration curve for each instrument. The same transformers should not, however, be used both for instrument work and circuit-breaker work. These transformers have sufficient capacity to operate relays or trip coils and will have an error in ratio not exceeding about 10 per cent. where the load at 4 amperes does not exceed exceed 25 volt amperes at 25 cycles or 55 volt amperes at 60 cycles. They should not be used with relays where the circuit-breaker trip coil is in series with the relay.

Through-types.—Types FS and FB (dry type) indoor transformers have a rated voltage of 2300, test voltage 10,000 for 1 minute, for 25 to 133-cycle circuits. These transformers in capacities up to 6000 amperes have a potential rating of 2300 volts. By the use of longer insulating tubes over the primary conductor, they may be used at higher voltages. In sizes up to and including 1000 amperes, they have a capacity of 25 volt amperes and are compensated for $12\frac{1}{2}$ volt amperes; above 1000 amperes they have a capacity of 50 volt amperes and are compensated for 25 volt amperes. These "through-type" transformers have no primary windings but slip over a cable, stud, or bus bar, which forms the primary of the transformer. The type FS is intended for cables and round studs, and the type FB for rectangular bus bars.

Short Circuits.—The momentary current due to a heavy short circuit on a large system is extremely great, and the mechanical stresses set up between the primary and secondary windings of a current transformer due to this current are extraordinarily large. The "through-type" of transformer is the only type in which these stresses are balanced up within the transformer itself; and they are therefore of special value where, due to special conditions, other types of transformers are liable to overstrain from such stresses.

Outdoor Types.—Types MA, MB or MC (dry type) outdoor transformers have rated voltage of 6900, 138,000 and 23,000; test voltage of 16,500, 33,000 or 52,200 for 1 minute; for 25 to 133 cycle circuits; capacity 50 volt amperes, compensated for 25 volt amperes. These transformers are mounted in cast-iron end caps with the leads extending downwards through suitable bushings. The transformers are impregnated with an insulating compound which thoroughly seals up joints between the laminations and end caps.

Fig. 129.—Westinghouse outdoor oil immersed current transformer 66 K.V.

Oil Insulated.—Types OA, OB or OC (oil insulated) transformers have a normal voltage of 34,500, 44,000 or 66,000 and a test voltage of 69,000, 88,000 or 132,000 for 1 minute; for 25 to 133 cycle circuits; capacity 50 volt amperes, compensated for 25 volt amperes. These transformers are designed for separate mounting, in compartments or otherwise. They are heavily insulated between primary and secondary windings and form a barrier of great strength between the line and the instrument circuits.

Double Secondary.—In cases where it is desirable to operate relays or circuit breakers together with indicating instruments or watt-hour meters, transformers having two independent secondary circuits can be furnished. The instruments can then be isolated from the relays or circuit breakers, and the accuracy of the former will be unaffected by the heavy load represented by the latter.

Outdoor transformers like Fig. 129 differ from the indoor type only in having high voltage outlet bushings suitable for outdoor service.

Voltage Transformers.—These are made either dry type or oil insulated. The dry type voltage transformers are mounted in end frames and are adapted for use on voltages up to 6000. The end frames of transformers up to and including 2000 volts have lugs cast on them for mounting fuse blocks.

Oil Insulated Voltage Transformers.—The oil insulated type voltage transformers are designed for use on voltages from 2300 to 66,000. Up to 6900 volts they are mounted in cases made to fit in cells or in the limited space behind switchboards. For voltages up to 6900, they are mounted in cast-iron cases provided with mounting lugs. For voltages above 6900, the transformers are built for floor mounting. For voltages of 4000 to 6900 inclusive, the transformers are so designed that the high voltage leads can be brought through either the top or the sides of the case, by means of the extra bushing holes and flanges. This feature is of particular advantage in switchboard wiring. Oil insulated transformers for outdoor operation like Fig. 130 can be furnished for standard voltages.

Fig. 130.—Westinghouse outdoor oil immersed potential transformer 66 KV.

The ratio of transformation should be such as to give a nominal voltage of 100 on the instruments. Thus, for a 2200-volt circuit, a 2000–100 ratio should be used, making the normal voltage on the instruments 110.

For protection against line surges, transformers designed for voltages of 22,000 and above, have choke coils mounted in their cases and connected between the transformer windings and the line.

Outdoor Metering.—These equipments as shown in Fig. 131 are designed for supplying service from high voltage transmission lines where the expense of a substation is not warranted, these metering equipments being furnished enclosed in weatherproof casings. Each equipment consists of a standard polyphase watt-hour meter, two current transformers, a polyphase voltage transformer, and three choke coils to protect the transformer windings against high-frequency disturbances; all enclosed in a sheet steel case with cast-iron cover. The sheet steel case is subdivided into 2 compartments, one of which is filled with oil in which the transformers and choke coils are immersed, while

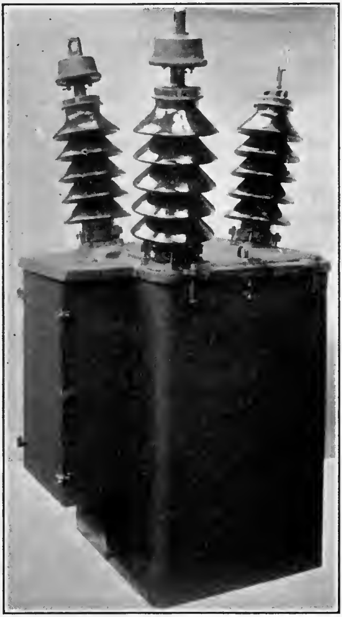


FIG. 131.—Westinghouse outdoor metering equipment.

the other serves to enclose the meter and meter panel. On the meter panel are also mounted two fuses to protect the voltage circuit of the meter and two calibrating links located in the current circuit of the meter. The meter may be read or checked upon opening the hinged door which covers the entire front of the meter compartment. The arrangement is such that the entire outfit, including meter panel, can be raised out of the tank without disconnecting the meter leads.

CHAPTER VIII

LIGHTNING ARRESTERS

The apparatus furnished for the protection of electrical equipment against the effects of lightning or static disturbances of any kind is usually considered as part of the switching devices and is frequently included in the same contract as the switchboard and the switching apparatus. For this reason it seems logical to take up its consideration in this book after the circuit breakers, relays, meters and instrument transformers.

Terms.—Lightning, from the protective standpoint, is a term used to cover all kinds of disturbances in electrical transmission systems that take the form of high voltage. There are two kinds of lightning, viz.: that due to atmospheric lightning, and that due to internal disturbances in the line itself. Lightning arresters are designed to take care of atmospheric lightning and those internal surges that are transient in nature, but not those that are continuous.

Cause.—Atmospheric lightning is due to discharges that occur between two oppositely charged clouds or between a cloud and the earth.

Direct Strokes.—When a discharge from a cloud strikes an electrical conductor directly, it almost always breaks down the insulation at or very near that point. It rarely travels along a transmission line far enough to reach an arrester and if it did it would probably destroy any type of arrester except possibly an electrolytic one. Arresters are not designed, therefore, to handle direct lightning strokes. It is usually the line insulators rather than the station apparatus that are injured by these direct strokes and they are best protected by overhead ground wires well and frequently grounded rather than by arresters.

Induced Strokes.—By far the greater number of disturbances in transmission systems due to atmospheric lightning are induced therein by discharges between clouds overhead or between a cloud and the earth in the vicinity.

Surges.—Internal surges are caused by any change in the load conditions. They may be either transient or continuous. Transient surges are caused by sudden changes of loads such as are occasioned by switching, the operation of circuit breakers, etc. They are usually comparatively unimportant but may be quite severe where a very heavy current is broken suddenly. Continuous surges are caused by arcing grounds which result in occillations of great power at a frequency usually a few thousand cycles per second. This frequency is inherent in the line and is determined by the capacity, resistance, and inductance of the line. Surges are very destructive and frequently result from breakdowns of insulation caused by induced lightning. Lightning arresters (except the electrolytic for a limited time) cannot handle continuous discharges such as these without being destroyed by overheating. Arresters do protect against arcing grounds, however, by protecting against the induced surges that are their primary cause in so many cases.

Displaced Neutral.—On a transmission line another cause of trouble that results in a continuous high voltage is a displaced neutral due to a ground on one phase of an ungrounded neutral system. This raises the voltage of the other phases above ground abnormally. In the case of transformers of high ratio this effect may appear even on the opposite side of the transformer and cause arresters to discharge continuously and be destroyed without apparent cause, inasmuch as the ground may exist a great distance away and on a different circuit.

The arresters described in this book are designed to take care of atmospheric lightning and transient internal surges but not of continuous surges.

Importance of Good Ground.—Too much importance cannot be attached to the making of proper ground connections. These should be as short and straight as possible. A poor contact will render ineffective every effort made with choke coils and lightning arresters to divert the static electricity into the earth. It is important, therefore, not only to construct a good ground, but in doing so to appreciate thoroughly the necessity of avoiding unfavorable natural conditions. Many lightning arrester troubles are traceable directly to poor ground connections.

Connection to Existing Grounds.—Direct connection to an underground pipe system (such as a city water main), furnishes an excellent ground, because of the great surface of pipe in contact with the moist earth and the maximum number of alternative paths for the discharge. A supplementary ground line should always be connected to the structural steel framework of the station, and to any nearby trolley rails. In water power plants the ground should always include a connection to the pipe line or penstock and to the case or frame of the apparatus to be protected.

Ground Conductor.—For the conductor between the arrester and the ground connection, either strap copper or copper tubing should be used. It is important that a conductor having the greatest possible superficial area be used, inasmuch as high frequency discharges are carried almost wholly on the surface of the conductor. Strap copper, having a section say $\frac{1}{32}$ inch by $1\frac{1}{2}$ inches, makes a good conductor for the average conditions. Such a ground conductor may be fastened directly to the station structure with wood screws The course of the ground conductor should be direct and have few turns—the fewer the better.

D.C. Arresters.—For direct-current service, lightning arresters are required for comparatively low voltages, but of high discharge capacity. The most satisfactory arresters, in order to adequately protect motors, generators and converters, must have the ability to discharge static at the lowest possible voltage rise above normal operating voltage, without danger of the generator current following and destroying the arrester. In general direct-current arresters are of two kinds: first, those which allow the generator current to follow a discharge when normal voltage is established and then disrupt it; and, second, those in which the generator current does not follow a static discharge. The latter type requires no resistance in the static discharge path, as in the case of the first type, to limit the generator current, and provides the greatest freedom for discharge of static and the lowest voltage discharge point.

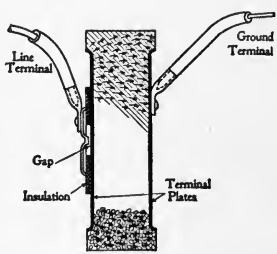


Fig. 132.—Multipath lightning arrester.

Multipath Arrester.—For A.C. or D.C. service for voltages not exceeding 1000 a "multipath" arrester, Fig. 132, has been developed by the use of a carborundum block fastened between the two terminal plates and allowing the static discharge to spread itself over a number of minute discharge paths. The normal voltage between the line and the ground is divided into so many minute gaps that the voltage across each gap is too small to maintain an arc after the discharge has passed.

Condenser Arrester.—One form of condenser arrester consists of a condenser alone; the other consists of a condenser in series with a spark gap, the condenser being shunted by a high resistance. The condenser is of the flat plate unit-form, which, in case of burnout, is easily exchanged without the necessity of dismounting the arrester. The condensers have a capacitance of one microfarad, which is equivalent in capacity to 100 miles of average line.

In the arrester without gap the condenser is connected directly across from line to ground, whether mounted on pole or car. Direct current cannot pass through a condenser, and there is, therefore, no leakage. The condenser is charged to normal voltage, but as soon as static surges appear the condenser discharges these surges at any voltage above normal. The use of the arrester without gap is important in the protection of apparatus having weakened insulation. Many railway cars are operating with motors that will not stand a breakdown test at the voltage necessary to bridge an arrester gap, but with this type of arrester they are given protection.

In the arrester with gap the principal differences are that the condenser is always discharged and, therefore, affords a slightly increased capacity for discharge of any static wave of great volume. The use of the gap also provides a means for testing the operation of the arrester by the use of tell tale papers and provides an easy way to make and break the circuit for testing the condenser.

Non-arcing Type.—One of the first successful high voltage arresters for A.C. service was based on the discovery of "non-arcing metal" by Mr. A. J. Wurts. The peculiar property of this metal is that an alternating current will not maintain an arc between adjacent cylinders of this metal, provided the voltage is not too high, and that the power current that followed the lightning discharge does not vaporize too much of the metal. The first condition was met by having a fairly large number of very small gaps in series, and the second condition gave no trouble on the early high voltage installations where the amount of power current was comparatively small. For large amounts of power it was necessary to use resistances in series with the spark gaps to limit the current and these resistances reduced the effectiveness of the arresters. For very high voltages different schemes were used to reduce the number of gaps required and it was found that by shunting a certain number of these gaps the effectiveness of the arrester was increased.

Fig. 133 shows an arrester of this design intended for service on 6600-volt lines where the capacity does not exceed 2000 K.V.A. The non-arcing cylinders are contained between porcelain insulators in such a way that the seven cylinders in each of the two sets have air gaps of about 1/32 inch between adjacent cylinders. The marble slab forming the base of the arrester also has mounted on it two graphite resistance rods shunting some of the gaps. Modifications of this scheme were used for the "low equivalent," "multigap," "multiphase" and similar "shunted gap" arresters that were installed before the electrolytic arresters were brought out and which are still giving good satisfaction in many plants operating at voltages as high as 88,000.

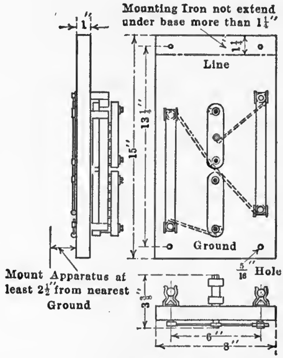


FIG. 133.—Non-arcing arrester.

Multi-chamber Type.—The arresters previously described are a few of the many types made by the Westinghouse Electric & Manufacturing Company for moderate voltage circuits, and the General Electric Company have a somewhat similar line of arresters. For use on A.C. systems up to 3000 volts Schweitzer & Conrad Inc. build the multi-chamber arrester which consists of a number of discharge gaps connected in series with a resistance and mounted in a porcelain housing. This housing is a porcelain tube closed at both ends, except for a venting hole at the lower end. The mounting bracket is an integral part of the main housing and is adapted for either cross arm or wall mounting.

Operation.—The operating element of the arrester consists of five series gaps, each gap being mounted in a separate cylindrical chamber in a block of insulating material. These cylindrical chambers are open only at one end, and the discharge gap in each chamber is located near the closed end.

When a discharge passes through this arrester, the heated air back of each gap in the closed end of the respective chambers blows the arc out towards the open end of the chamber. This blowout action is very effective in extinguishing the arc and in rupturing the dynamic current which tends to follow the high voltage discharge.

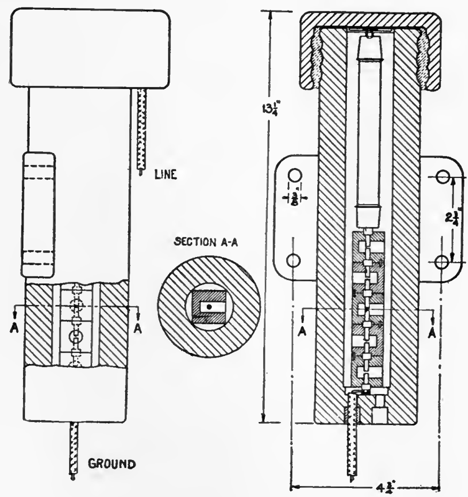


FIG. 134.—Schweitzer & Conrad multi-chamber arrester.

As will be seen from Fig. 134, the insulating blocks are assembled so that the openings of adjacent chambers are diametrically opposite in the porcelain tube, making the path between adjacent gaps a maximum. This arrangement prevents bridging of the gaps by the arc or the arc vapor. The spark gap points are made of a non-arcing metal, which feature assists in extinguishing the arc.

Electrolytic Type.—While arresters of various types have been developed and are in service for high voltage installations, the electrolytic arrester has been found to furnish the maximum amount of protection and is the one most frequently employed by the Westinghouse Electric & Manufacturing Company and the General Electric Company, where continuity of service and value of the equipment to be protected makes it advisable to furnish the highest grade of equipment.

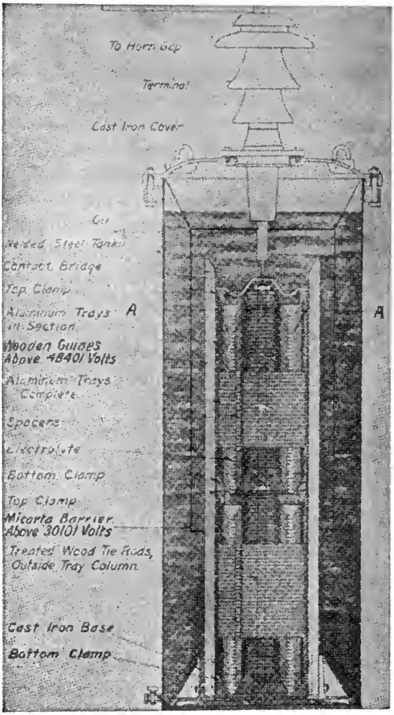


Fig. 135.—Section of electrolytic lightning arrester.

Arrangement.—The essential parts of an electrolytic lightning arrester of Westinghouse design are shown in Fig. 135. The arrester consists of a system of aluminum cup shaped trays (supported on a porcelain and secured in frames of treated wood) arranged in a steel tank. The system of trays is electrically connected between line and ground, and between line and line. These trays contain a liquid electrolyte which on charging the arrester forms a film on their surfaces. This film prevents flow of current at normal voltages, but forms a free path for abnormal voltages or static discharges. Upon cessation of the abnormal stress the film regains its original resistance practically instantaneously, and prevents power current from following the discharge.

These aluminum trays are separated from each other by porcelain spacers arranged around the edge of the tray insuring positive separation and ample space for the escape of such gases as are formed during a heavy discharge. The porcelain spacers vary slightly in thickness, but this does not affect the operation of the arrester because the resistance of the cell resides primarily on the film of the tray and only slightly in the electrolyte. The trays are thoroughly treated chemically and electrically and are shipped out with the film already built up.

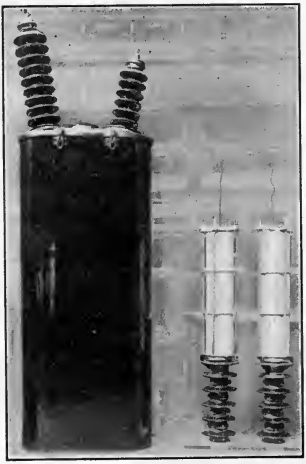


FIG. 136.—Westinghouse electrolytic lightning arrester 132 K.V. Assembly of complete pole and tray column.

The General Electric arresters have the same main features but the details of construction are somewhat different.

132 K.V. Arrester.—Fig. 136 shows the arrangement of tank bushings, trays and supports used for electrolytic arresters for 132 K.V. service. As may be noted the tank is elliptical in shape with two terminals, the longer one connecting to the line circuit, the shorter one being used for the neutral connection. These tanks are thoroughly grounded and the aluminum trays are mounted on insulated supports and provided with barriers to obviate the likelihood of any high voltage jumping from the trays through the oil to the grounded tanks.

Gaps.—For high voltage service, horns with sphere gaps are provided and charge and discharge resistors furnished, these being connected in series with the aluminum trays and under normal conditions there is no voltage impressed on the trays. Abnormal voltage or high frequency surges will bridge the gaps allowing current to pass into the trays.

The horn-type gap was first used and is still employed in many cases. It is so arranged that any arc forming will follow the natural tendency to rise and will be extinguished by the magnetic blowout effect and the increased width of spacing at the top of the horn.

Sphere Gaps.—A sphere gap has a shorter dielectric spark lag than the horn gap, *i.e.*, it has a greater speed of discharge. The use of sphere gaps on high voltage arresters considerably increases the protection afforded the apparatus. On the lower voltage arresters the rods forming the horn gaps are of such a diameter that they have practically the same effect as sphere gaps; *i.e.*, the gap is so small in proportion to the diameter of the horn that the effect is the same as if sphere gaps were used. Where sphere gaps are employed, they have horn extensions rising above the spheres to assist the arc to rise and thus be quickly extinguished.

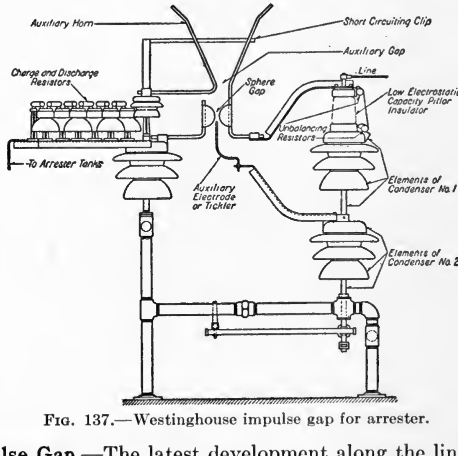


FIG. 137.—Westinghouse impulse gap for arrester.

Impulse Gap.—The latest development along the line of high speed gaps used by the Westinghouse Company is the impulse gap shown diagrammatically in Fig. 137. This impulse gap is stated to excel every other known gap in assisting arresters to give protection from lightning and other high frequency or high voltage disturbance. The original horn gap has considerable time lag, allowing high frequency surge before discharging and giving protection. The sphere gap partly prevents this situation by eliminating the time lag so that all frequencies are discharged at the same voltage. The impulse gap has a negative time lag, *i.e.*, the higher the frequency the lower the voltage at which the gap discharges. Thus the impulse gap automatically selects the dangerous surges and gives protection more quickly than any other known form of gap. With the impulse gap the high frequency discharge voltage may be as low as two-thirds or even one-third of the normal frequency value. It is therefore possible to use a gap setting that will permit of the desired degree of protection against dangerous surges and not permitting too frequent discharging on minor surges at normal frequency.

Gap Speed.—The high speed of the sphere gap as compared with the horn gap is due to the elimination of the time required to build up a sphere of equi-potential surface on the discharge part of the horn gap. The sphere of the sphere gap provides at once for this, and practically eliminates corona. It does not, however, give the desired protection against the steep-wave front or high frequency surges due to its inability to discharge these disturbances at lower voltages than the normal frequency setting of the gaps.

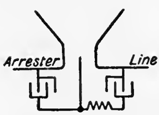


Fig. 138.—Schematic diagram of impulse gap.

In the impulse gaps, however, the advantage of high normal frequency setting of the gaps can be had without the corresponding disadvantage of reduced protection, since the high frequency breakdown value of the impulse gaps is much lower.

The schematic diagram of the impulse gaps is shown in Fig. 138. This impulse gap uses a circuit that at normal frequency is balanced as to voltage, but becomes unbalanced and starts a discharge in case of any high frequency surges. At normal frequency there is no difference of potential between the mid-point of the condenser and the auxiliary electrode midway between the auxiliary horn and sphere gaps. A high frequency, however, passes freely through the condensers and piles up its full voltage across the resistance and carries across one-half of the total gap. This gap, therefore, breaks down, resulting in the total voltage being impressed on the remaining gap which breaks down in turn. Breakdown at each half of the gap is facilitated by the fact that the auxiliary electrode is small in size, having needle gap characteristics so that the discharge voltage at each half of the gap is about ¼ rather than ½ of the total gap between the spheres.

Oxide Film.—Owing to the use of the liquid electrolyte, the necessity for periodical charging and the comparatively high price of the aluminum cell electrolytic arrester, the oxide film arrester has been developed by the General Electric Company who have had some in service, experimentally, for some time and have lately placed them on the general market. This oxide film arrester depends for its functioning on the fact that certain dry chemical compounds, such as lead peroxide, can be changed rapidly from a very good conductor to an almost perfect non-conductor, litharge, by the application of a slight degree of heat, such as would be caused by the passage of a lightning discharge.

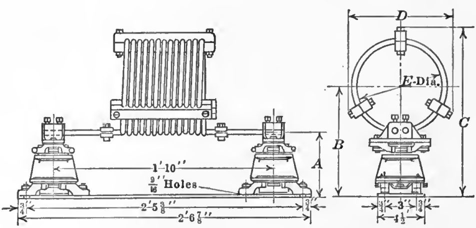


Fig. 139.—Cylindrical choke coil.

Choke Coils.—Whenever a surge of high frequency or steep-wave front due to lightning or any other cause travels along a line and strikes an inductive winding, it builds up a high voltage to ground. Choke coils are frequently furnished for use on line circuits to take the brunt of such surges and to provide a point where the lightning arresters can be connected in to secure the maximum protective effect. Besides relieving the end turns of the power apparatus from the first shock of the surge and flattening it out before it can enter the power apparatus, it delays the progress of the surge and the piling up of the voltage momentarily at the line, thus giving the arrester more time and more tendency to discharge and relieve the line.

While a very small choke coil has low protective power, very large coils will introduce excessive reactance in the line and impair the regulation. It is, necessary therefore, to choose for any service a choke coil proportioned to the needs of the apparatus.

Cylindrical Coil.—Fig. 139 shows a choke coil suitable for 50 K.V. operation. The coil consists of 20 turns of aluminum rod formed into a cylinder 15 inches in diameter, and provided with bracing clamps to rigidly separate the turns and to give mechanical strength to the helix. Similar coils 9 inches in diameter can be supplied having a fewer number of turns and approximately one-sixth the impedance.

Horn Arresters.—For plants of moderate capacity for outdoor high voltage service, particularly where the lightning conditions are not very severe, the cost of electrolytic lightning arresters may not be justified by the value of the equipment which they are protecting. For such cases, horn type lightning arresters can be utilized to advantage.

Railway Industrial & Engineering Type.—Such arresters made by the Railway & Industrial Engineering Company are usually combined with triangular shaped choke coils as shown in Fig. 140. With this arrangement, one side of the choke coil acts as one of the horns of the arrester. The coil is used in this way, first as a magnetic blowout to hasten the travel of the arc up the horns, and second to increase the speed of operation of the arrester. The incoming line is connected to the outside turn, and the path of the power circuit is around the coil and out through the center, so that the surge entering the coil meets its first obstruction at the first sharp upward turn of the coil opposite which is mounted the ground horn. The voltage will build up at this point and is reflected back by the other turn toward ground. Due to this construction the gaps to ground may be set approximately 50 per cent. greater than the ordinary shunted horn gaps with the same protection obtained.

For more severe lightning conditions the type of horn arrester shown in Fig. 141 is used. This arrester is similar to the one previously described except that a reactance coil is connected in series with the high capacity resistance in the ground circuit. An auxiliary horn gap shunts both the reactance coil and the resistance thus giving a direct path to ground to a surge of such

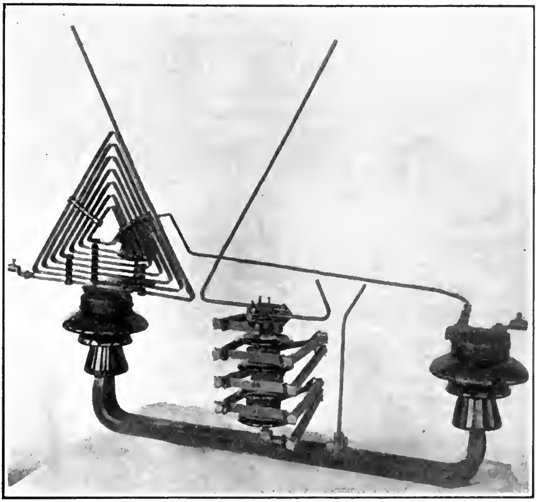


Fig. 140.—Railway & Industrial Engr. Co. lightning arrester type "WB."

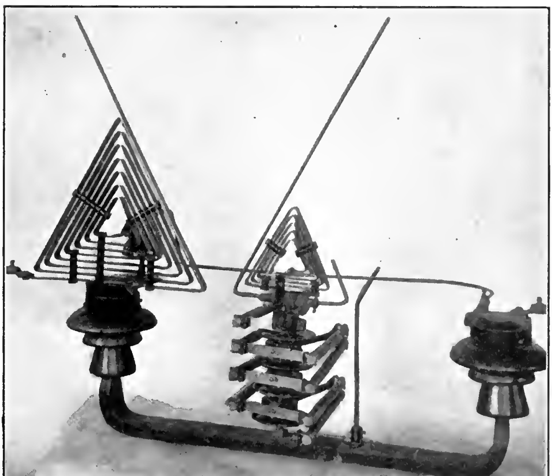


Fig. 141.—Railway & Industrial Engr. Co. arrester with resistor.

capacity that it cannot be discharged quickly enough through the reactance and resistance. This reactance is used principally to relieve the resistance of the heavy strain by smoothing out the surge before it reaches the resistance. The use of the reactance coil in no way interferes with sensitiveness of the arrester.

S. & C. Horn Type.—Horn-gap arresters are also built by Schweitzer and Conrad in the form of the graded resistance arrester which consists essentially of a horn gap and a number of resistance units so arranged that as the arc rises from the lower part to the upper part of the horn, the resistance is automatically cut into circuit step by step, so that the current is rapidly cut down and the arc is easily broken when it reaches the upper part of the horn. See Fig. 142.

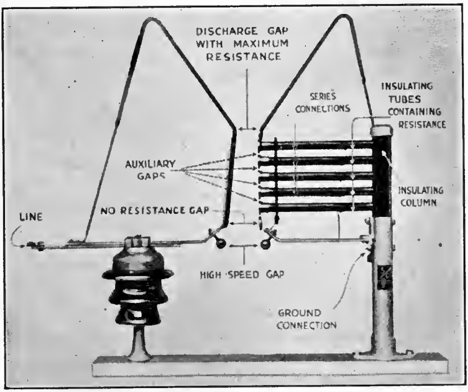


Fig. 142.—Schweitzer & Conrad graded resistance lightning arrester.

With any potential rise on the line or apparatus protected by the arrester, the arc will start across the smallest gap which has all the resistance in series. If the potential rise is of low energy capacity, the current flowing through this gap and total resistance may be sufficient to keep the voltage down to approximately normal. If the current flowing through this gap and resistance is insufficient to keep the voltage down, the arc will break across the next lower step and a larger current will flow. If this current is still insufficient to keep the voltage down to safe value, then the next lower step will arc across, etc., until the "no resistance" or lowest step is reached, when the system will actually be short-circuited and practically unlimited current can flow.

Schweitzer & Conrad arresters are regularly furnished in a number of combinations. By the addition of a choke coil, a disconnecting switch, and a load fuse, a complete protective combination can be made on one channel base, so that the installation of the whole combination is quite simple as compared to the installation of separate pieces of apparatus. One of these arrangements is shown on Fig. 143.

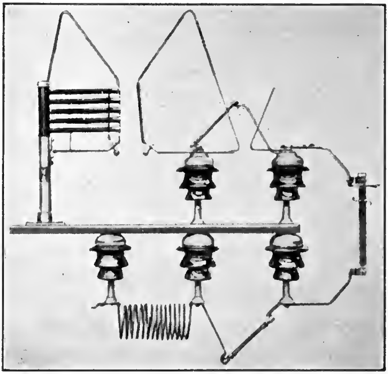


FIG. 143.—Schweitzer & Conrad protective combination.

Reactors.—Choke coils, in addition to being used for lightning protection, are employed for the purpose of current limiting reactors in large power plants, and have been connected in the circuits of generators, feeders and bus bars.

In large systems current limiting reactors have been installed for the purpose of limiting the amount of current that may flow from any part of the system into a short circuit in the apparatus or the connections inside the station or close to the station. By so limiting the abnormal flow of current into a short circuit, the generating system as a whole is relieved from the possible disastrous effects of short circuit. At the time of the disturbance on the system the extra load thrown on the generators by the energy fed into the short circuit is such that the generating frequency and voltage are momentarily lowered and the reactors will tend to reduce this extra load on the system and minimize the change in frequency that often throws out of step the synchronous apparatus in the substations and the generators at other connected stations.

Some of the earlier turbogenerators particularly for 25-cycle service, had a comparatively small amount of internal reactance, but the manufacturers of turbogenerators are now recommending a total generator reactance, internal and external, of from 10 to 15 per cent. and turbogenerators are now usually so designed as to be able to withstand mechanically a dead short circuit across their terminals with full field excitation. Arrangements are usually made to build such turbogenerators with fairly high internal reactance and to brace their coils sufficiently to withstand the mechanical stresses set up at the time of short circuit.

Breakdowns.—Experience seems to show that a large percentage of the breakdowns originate in the feeder circuits, and the use of feeder reactors for minimizing the trouble is employed in many cases. These feeder reactors reduce the stresses upon the circuit breakers, and frequently make it possible to use smaller and cheaper breakers in moderate capacity plants than would otherwise be possible. As the ratio of the feeder capacity to the total station capacity in large plants is usually small, a small percentage reactance on a small feeder reduces the short-circuit current to practically a negligible quantity. The small percentage of reactance also makes negligible the effect of the regulation of the feeder.

With reduction in the feeder short-circuit current, the relay system can be made far more selective, the voltage in the system will not be materially affected, the energy fed into the short circuit will not tend to slow the generators down, reducing a change in the system frequency, and synchronous apparatus on other parts of the system will not fall out of step. The protected feeder will be automatically disconnected from the system without interruption of service to the remainder of the system.

Makers.—Current limiting reactors for various services have been furnished to many of the largest plants by the Metropolitan Engineering Company, the General Electric Company and the Westinghouse Electric & Manufacturing Company.

Metropolitan Engineering Company Reactors.—The appearance of the coils is clearly shown in Fig. 144, this showing an installation of porcelain-clad reactors of the Metropolitan

Engineering Company. The coil consists of a series of horizontally wound spirals supported and insulated by porcelain arms having suitable recesses for the winding. The arms are assembled radially as vertical walls between a hollow core of concrete or soapstone, and an outer enclosing wall built up of special porcelain segments. These cellular compartments, so formed, allow natural ventilation for the coil. The entire coil is supported at the two ends by heavy concrete headers securely held by a

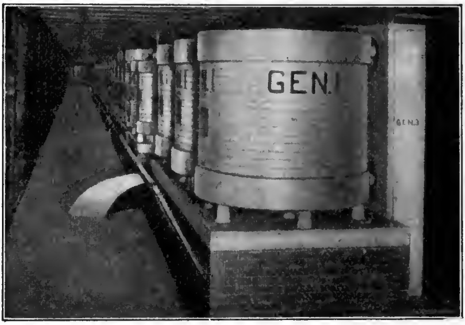


FIG. 144.—Reactor of Metropolitan Engineering Co.

number of brass bolts with insulating mica tubes passing through the heads and wall of the special porcelain segments from top to bottom. Ventilating holes are connected with each vertical cellular compartment of the coils.

Porcelain Clad.—These reactance coils are porcelain clad, and the windings are embedded at their supports in walls of smooth porcelain insulators, giving fireproof construction with good electrical and mechanical qualities entirely unaffected by high temperatures. The smooth glazed finish of the porcelain facilitates inspection and cleaning of coils, and the almost monolithic construction insures mechanical safety.

Mutually Reactive Coils.—For combining in one unit the protection desirable for the circuit of the generator bus bar and feeder, mutually inductive reactors have been designed, these consisting essentially of reactors with a tap in the middle, the current being taken in at this point and taken out at the two opposite ends as shown diagrammatically in Fig. 145. These mutually inductive reactors protect the generator from excessive short-circuit currents, protect and localize any trouble on a bus section, and materially reduce the short-circuit current into feeder troubles.

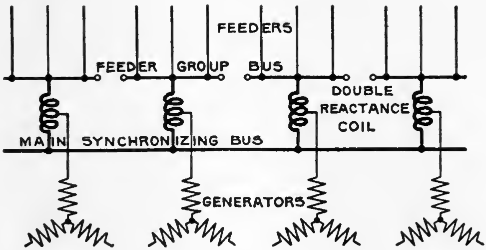


FIG. 145.

This combined system of coils is better than the independent coils, in requiring much less space, in utilizing the mutual inductance between the two sections of the coils to limit the current to a greater extent for a given amount of copper, and to reduce the short-circuit disturbance, as the current in the short circuit is made to keep up the pressure on the rest of the system.

In all cases the reactance coils should be placed as close to the bus as possible to protect the bus under the greatest number of conditions, so that the reactance coils should be considered as a part of and made as reliable as the high tension bus.

Semi-porcelain Clad.—A modification in the construction of these Metropolitan coils is known as the semi porcelain clad reactor. With this arrangement the coils are made up of a number of concentric co-axial solenoids in parallel, designed to give a uniform potential gradient from top to bottom. The insulating space required between layers is practically eliminated, this resulting in a large reduction in size and increased efficiency of coils. While the coils are cylindrical they are assembled in rectangular forms with porcelain insulators at the four corners, these insulators being of L shape with micarta barriers passing in front of the coils.

G. E. Reactors.—General Electric reactors are of the "cast in" type, *i.e.*, the windings are rigidly held in place by vertical concrete supports which are cast around the turns after the coil has been wound in a form built up of steel plates as shown in Fig. 146. After the concrete has set, the forms are removed and

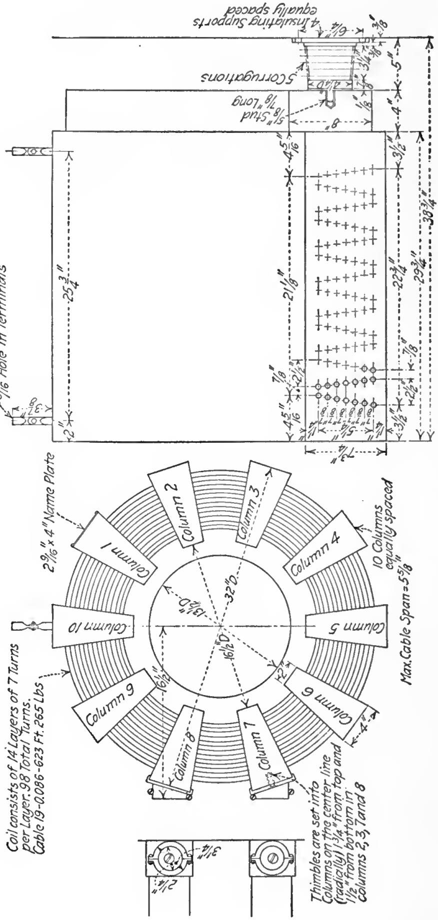


FIG. 146.—Construction of cast-in reactor.

the concrete is cured by treating with high-pressure steam. This method will give twice as much aging as would be obtained by natural processes in several months. The reactor is then sand blasted, thus giving both the copper and concrete a very finished appearance as shown in Fig. 147.

The number of supports depends upon the current rating and the stresses produced by short circuit current. Intimate contact between the winding and the supports insures a very rigid structure. There are no through bolts in the coil, and the possibility of a short circuited winding due to arc over from the terminals to the bolts is therefore eliminated.

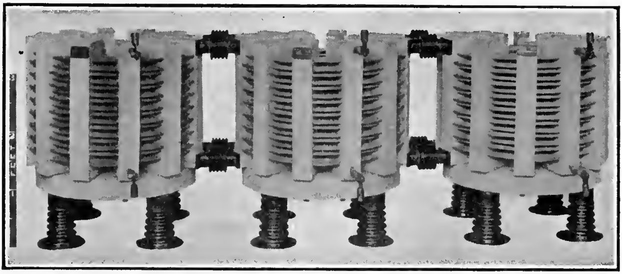


Fig. 147.—G. E. Co. "cast in" type power limiting reactors.

Windings.—The windings consist of one or more cables in multiple. These may be solid or, if necessary, concentrically stranded with asbestos paper between layers in order to keep to a minimum the loss due to eddy currents.

The turns are wound radially in conical layers with adjacent layers inclined in opposite directions. Ample spacing is provided between turns and layers, depending upon the circuit voltage and the K.V.A. capacity of the reactor. Any two adjacent layers converge toward the point of interconnecting crossover, where the voltage between layers is consequently equal to the voltage between turns. All crossovers are embedded in the concrete supports so that all of the cable exposed is concentric, and full distance is maintained between turns at these points.

The terminals consist of heavy pressed copper tube brought out radially or circumferentially from one of the coil supports. The conductors are brazed into these terminals, thereby eliminating the possibility of an open circuit at these points, due to over heating by short circuit current.

If necessary the coil may be divided into two sections wound in opposite directions, in which case the bottom end of the top section and top end of the bottom section are usually brought to the same terminals, and the other ends of the sections are each brought to a terminal which is bolted to a vertical copper bar or strap joining the two. Thus the coil is symmetrical about a plane perpendicular to the mid point of its vertical axis.

Base.—The concrete supports are uniformly spaced around the coil. They rest on a heavy concrete base ring having a rectangular cross section, which serves to distribute the weight of the coil. The supports and base are bolted together by means of bolts fitting into threaded thimbles cast in the bottom of each support.

Insulators.—To insulate the structure from ground the base is set on pedestal-type porcelains to which castings are fitted at each end. The top castings are provided with tap holes in the center by means of which they may be bolted to the base ring. The bottom castings are provided with holes for bolting to the floor.

Installation.—For a three phase installation, three single phase reactors may be installed in a row, at the corners of an equilateral triangle, or one above the other. When required by the magnetic forces the reactors are braced from each other and from the wall by means of corrugated porcelains which fit into castings attached to the concrete columns. A three-phase reactor may also consist of three separate windings one above the other, cast into the same supports. Where space is available, the preferred method however, is to install each reactor in a separate cell.

Shunting Resistance.—In some of the latest designs, the reactors are supplied with shunting resistors connected across the terminals of the coil. These resistors will absorb impulse voltages and prevent the building up of excessive resonant voltages. Under normal conditions, the loss in the resistor is very small, but in case of high frequency surges, the shunting path is very desirable in that it tends to dissipate the energy of the high frequency oscillation. It is an interesting fact that these resistors have the valuable property of high resistance at low voltages and low resistance at high voltages. The resistors consist of resistance rods embedded in concrete blocks which are placed inside the reactor and rest upon the reactor base.

Westinghouse Reactors.—The current limiting reactors of the Westinghouse Electric & Manufacuring Company are built either as single-phase units or as 3-phase. A typical single-phase coil is shown in Fig. 148, this having a rating of 100 K.V.A., 1000 amperes, 25 cycles or 8 per cent. on the basis of a normal 3-phase circuit, at 2200 volts with one coil per phase. As these current limiting reactors are air cooled a comparatively large area of conductor surface must be provided to dissipate the I^2R loss and since the area of a conductor, such as a cable, increases with the square of the diameter and the surface as the first power, it is obvious that the smaller the diameter of the cable the more efficiently is the copper worked. The copper represents the large part of the cost of a reactor hence the necessity to keep its amount to a minimum. This reasoning has led to the use of a fairly small size of cable and the use of a number of these in parallel to get the proper current-carrying capacity.

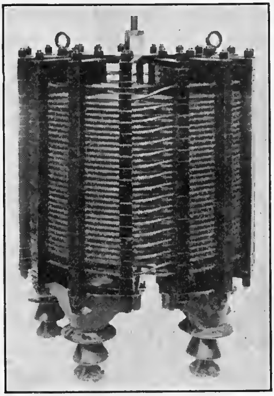


FIG. 148.—Westinghouse single-phase reactor.

Multiple Winding.—With a number of cables in multiple in a coil of this kind there is a tendency for these parallel circuits to have different ohmic and inductive characteristics unless special precautions are taken to see that the lengths and relative positions of the cables in the parallel paths are practically identical. If this is not done there will be circulating currents set up that will cause excessive loss and heating of the coils.

Large Reactors.—With a typical single-phase Westinghouse coil for use with a 3-phase generator of 21,100-K.V.A. capacity the normal full-load current is 1100 amperes and the coils are wound with seven stranded bare copper cables connected in parallel in such a manner that the paths are of substantially the same lengths and impedance. The seven cables are wound into grooves in specially prepared moulded fireproof cleats These seven cables enter the coils at seven equi-distant points around the inner periphery of the bottom layer of the coil. The first cable occupies the inner circumferencial row of slots for one-seventh of a turn and then passes out to the second row of slots and the second cable occupies the inner row. These two continue in this position for the second seventh turn, at the end of which they step outward one more row and the third cable enters on the inner row.

The moulded cleats with slots into which the cable is wound have holes in their ends through which brass rods covered by insulating tubes are placed for clamping the layers together securely. On the top and bottom of each tier of cleats is placed a nonmagnetic metal cleat that allows the coil to be clamped tightly together. The spacing between columns of cleats is close enough to prevent any appreciable deflection of the cable under the most severe short-circuit conditions. The tensile strength of the copper in the cable is sufficient to resist the magnetic stress tending to increase the diameter of the coil.

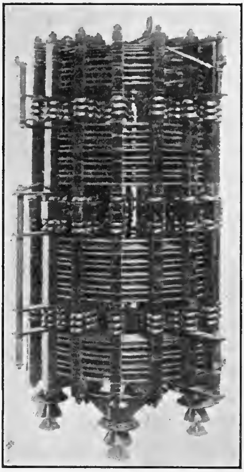


Fig. 149.—Westinghouse three-phase feeder reactor.

Supports.—The coil is supported on three nonmagnetic castings each of which spans four tiers of cleats. Into these castings are cemented insulators which rest on metal pins suitable for cementing or bolting to the floor. Two brass rods pass through the opening of the coil and are supported by porcelain bushings held in place by a three way support and on each end of the rod is provided a line terminal. All of the cables at one end of the coil are connected to one rod while the cables at the other end connect to the second rod.

Three-phase Reactor.—For 3-phase feeder circuits of moderate capacity a 3-phase reactor such as shown in Fig. 149 can be supplied. This shows a 440-ampere, 127-volt, 167-K.V.A. 25-cycle, 3-phase coil for use on a 6600-volt circuit. Such a coil gets the advantage of the mutual reactance between phases and it may be noted that the coils at the top and bottom are part of the same coil in one phase while the two wider coils in the middle are for the remaining phases. Such 3-phase coils can be installed in a much smaller space than three single-phase independent coils and the wiring of the plant can frequently be simplified by their use.

CHAPTER IX

REGULATORS

The switches, fuses, circuit breakers, relays, instruments, etc., all have their important functions to perform as part of the switch gear in a station but as practically all electrical energy is distributed on the constant potential system, the devices for maintaining constant potential are of vital importance in any plant. Where the circuits are few and all of about the same length and load conditions it is only necessary to maintain constant the voltage on the bus bars. Where there are many feeders with varying load conditions it becomes a matter of importance to be able to adjust the voltage on these feeders independently. The demand for this class of adjustment led to the development of feeder regulators.

FEEDER REGULATORS

Step Type Regulator.—The first type of regulator was a transformer with many taps and provision for connecting the feeder to any tap. This could be done by switches of various kinds and the natural development was to arrange the contacts in the form of a ring on a suitable faceplate and to provide a movable arm for connecting the feeder to any of the taps from the transformer. As the voltage was varied by definite steps, this type of regulator was known as the step type regulator. These regulators consist essentially of a dial or drum with a number of contacts or steps, connecting to taps brought out from the secondary of a transformer whose primary is usually connected across the feeder circuit. This feeder circuit is connected in series with the dial and a reversing switch so that a part or all of the secondary voltage of the transformer can be added to or taken from the bus voltage.

Reverser.—The moving arm on the dial type regulator is usually arranged so that in passing from the position of maximum boost the number of secondary turns in series with the circuit is reduced in equal steps until the turns are all cut out. Further rotation in the same direction throws over the reversing switch and then cuts in the same secondary turns in opposition to the main voltage until the position of maximum buck is reached, when a stop prevents any further rotation in that direction. A similar stop prevents overtravel in the position of maximum boost

Split Arm.—With this dial type regulator the contacts are mounted on a marble dial and a movable arm, spring actuated, is so arranged that it moves quickly from step to step without any possibility of stopping between steps and short-circuiting a part of the transformer. A modification of this arrangement has the contact arm split in two parts with a preventive resistor or reactor joining the two parts to obviate any chance of short-circuiting part of the transformer.

Limits.—For high voltage or heavy current capacity the step type regulator can be employed by the use of current or potential transformers or both, so that the current to be handled does not exceed 200 amperes and the voltage on the dial is not greater than about 2200 volts or about 440 K.W. maximum for the capacity of the feeder on which 20 per cent. regulation or 88 K.W. can be obtained.

For heavy service on circuits up to 6600 volts and for handling a greater voltage per step than the 20–25 that can be taken care of with an open air dial, a drum-type regulator is used having its switch and contacts immersed in oil. Regulators of this type can be built for 6600 volts, 200 amperes, 20 per cent. regulation or about three times the capacity of the dial type. For some classes of electric furnace work the drum-type regulator or a step by step device is employed with an induction regulator to give a smooth and continuous variation in voltage between steps.

Induction Type.—In most modern installations the induction regulator is used in preference to the step type as giving a more even adjustment of voltage, avoiding any winking of the lights and allowing for automatic operation in a simpler manner than the step type.

Induction type regulators are made for single-phase or 3-phase service and arranged for hand operation or motor operation, or motor operation controlled from a distant point, or for complete automatic operation by means of relays. The regulator for single phase circuits consists of a rotatable primary core and winding and a fixed secondary core and winding usually immersed in oil. The primary winding is connected across the line and the secondary is in series with the feeder. The voltage induced in the secondary depends on the relative position of the two coils and increases or decreases the feeder voltage by a practically infinite number of steps.

Where automatic operation is desired for either single or 3-phase regulation this is obtained by the action of a voltage relay either with or without a compensating device. This relay acts in conjunction with the motor on the regulator in such a way that as the load comes on or as the bus voltage drops the motor will turn the regulator in such a direction as to increase the voltage. By means of a compensator, which can be set for a certain ohmic and a certain inductive drop, the voltage at the point of distribution can be maintained constant, independent of the amount and power factor of the load if the total drop is within the range of the regulator.

While the illustrations and descriptions of induction regulators that follow are based on Westinghouse apparatus, the regulators made by the General Electric Company have many of the same features and the descriptions with slight modifications would apply in most cases to the General Electric devices.

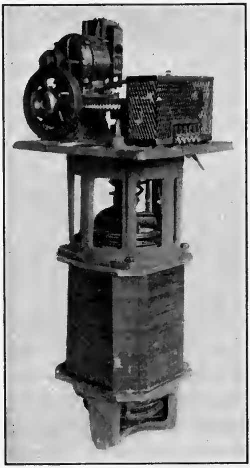


Fig. 150.—Westinghouse single-phase motor operated voltage regulator.

Single phase Type.—Fig. 150 shows a motor operated single-phase induction type regulator with the tank removed.

The regulation of feeder voltage is accomplished by turning the rotor, either by hand or electrically, so as to change the relation of the rotor winding to the stator winding. The regulation is smooth and gradual in either direction throughout the entire range of the regulator. The circuit is not opened at any point, the effect of the regulator being practically the same as would be obtained by changing the generator voltage.

The single-phase regulator is in effect a two-winding transformer, with the secondary winding arranged for connection in series and the primary winding arranged for connection directly across the line. With a transformer thus connected a voltage will be induced in the secondary that will add to or subtract from the feeder voltage according to the connections used.

Action.—With the regulator, the primary winding is the movable winding (the rotor) and the secondary the stationary winding (the stator). The current in the primary produces a magnetic field that induces a voltage in the secondary. The portion of this field passing through the secondary winding and consequently the voltage induced in that winding, depends upon the angular position of the secondary with respect to the direction of the primary field. The induced voltage is a maximum when the axes of the coils coincide; zero when the coils are at right angles to each other; and maximum in the opposite direction when the axes of the coils coincide but with primary coils reversed in position. This induced voltage in the secondary, therefore, adds to or subtracts from the feeder voltage by a value varying from maximum regulation to zero, according to the position of the coils.

Short-circuited Winding.—It is evident that a magnetic field is also set up by the line current flowing through the secondary windings (stator coils) which, if not neutralized, would produce a choking effect and lower the power factor in the feeder circuit. This choking effect would occur whenever the primary winding (rotor) is in any position other than where the axes of the two windings coincide—the positions of maximum "buck" or "boost"—being minimum near these positions and maximum when the axes of the two windings are at right angles to each other—the neutral positions. To overcome this choking effect, a short-circuited winding is placed in partially closed slots in the rotor core and at right angles to the primary coils; this short-circuited winding acts as a secondary to the stator coils and neutralizes their choking effect. By using a large number of turns of relatively small insulated wire in the short-circuited winding, the choking effect is neutralized with a comparatively small copper loss in the short-circuited winding.

Polyphase Regulator.—This regulator may be likened somewhat to a phase-wound polyphase motor. The regulator primary (rotor) is wound with a distributed winding of the same number of phases as there are phases in the feeder to be regulated and each phase is connected across a separate phase of the feeder.

The regulator secondary (stator), is made up of separate windings of the same number as the primary, and each of these separate windings is connected in series with one of the feeder wires.

Action.—The primary sets up a magnetic flux of constant value, which induces a constant voltage in each of the secondary windings. The induced voltage is added therefore vectorially to the feeder as the cosine of the angle between windings. As the position of the rotor is changed, the phase angles between the feeder voltage and the secondary voltage correspondingly changes, and the feeder voltage is either increased or decreased as the phase angle is less or greater than 90 degrees.

Since the polyphase regulator has windings distributed around the entire circumference of the rotor, these windings will also act as neutralizing windings for the various stator windings and no separate short-circuited windings, as in the case of single-phase regulators, are necessary.

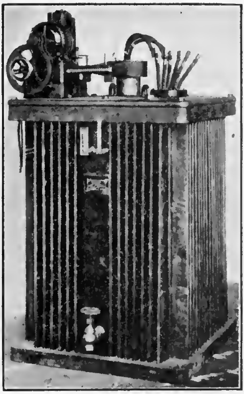


Fig. 151.—Westinghouse polyphase induction regulator motor operated.

Motor Drive.—In the standard regulators, the rotor is turned by a small alternating-current induction motor driven through a pinion, spur gear, worm, and worm segment (see Fig. 151). The motor is controlled non-automatically by a hand operated switch, or by an electrically operated switch with push-button control mounted in any convenient location; or automatically by means of relays and other accessories especially made for the service. The motor operated regulators are equipped with a hand wheel to operate them by hand in case of failure of the control circuit.

A relay switch is used to control the motor circuit so as to relieve the contacts of the primary switch from the necessity of carrying the current required to operate the motor. On the Westinghouse regulators this relay switch, called the secondary relay, is operated by a control circuit closed through a hand operated switch when non-automatic operation is used, a push-button switch generally being used—or through a primary relay when automatically operated. It is essentially an electrically operated double-pole double-throw switch.

Limit Switch.—This is connected in the operating circuit and actuated by the operating mechanism of the regulator, prevents overtravel of the rotor in either direction. It is combined with the secondary relay when that relay is mounted on the regulator top-cover; and when the secondary relay is mounted separately the limit switch is mounted directly on the regulator top-cover.

Primary Relays.—The voltage regulating primary relay is in effect a voltmeter having two sets of contacts that control the circuits operating the secondary relay, one circuit being closed when the voltage rises above a predetermined value and the other when it falls below another predetermined value.

Fig. 152.—Primary relay for induction regulator.

The primary relay shown in Fig. 152 is enclosed in a metal case with dustproof cover provided with a window permitting ready inspection of the operating parts. It has compounding coils so that as soon as a change in voltage causes either set of contacts to close they do not "chatter" but remain closed until the voltage returns to normal. Means are provided for adjusting the relay for different voltage variations and ranges.

No-Voltage Device.—A special primary relay having a no-voltage device can be supplied to cause the regulator rotor to be turned to the position of minimum voltage in case the power supply in the feeder circuit is interrupted. It, therefore, prevents the possibility of temporary overvoltage on the circuit when the power supply is again continued. A voltage transformer of the proper rating is used to reduce the feeder voltage to a value suitable for the primary relay. A compensator is a device connected to the feeder circuit at the station by means of a current transformer, and in connection with a voltage transformer, produces at the primary relay terminals a voltage proportional to that at the distributing end of the feeder.

Outdoor Type for Platform Mounting.—The outdoor induction feeder voltage regulators shown in Fig. 153 provide a means of obtaining good voltage regulation in outlying districts or on any other part of an alternating-current distribution system without the expense of housing—they fit in well with the other apparatus now being used so economically in outdoor substations and other outdoor installations.

Being entirely weatherproof and self-contained these regulators may be mounted on platforms constructed on poles or on the ground, protected by a fence or screen, in the same manner as transformers in outdoor substations. The only attention required is a general inspection for oiling the motor bearings and worm-screw mechanism, filling grease cups, and examining the relay contacts at regular intervals.

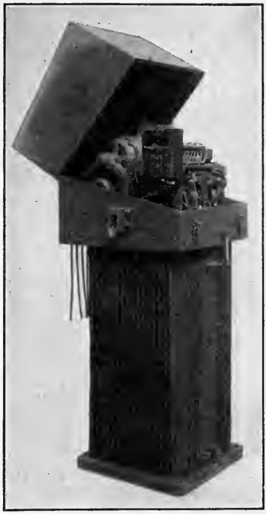


Fig. 153.—Outdoor type induction regulator—cover raised.

Mounting.—These regulators are made for mounting on any substantial flat surface, such as a platform between poles or on a platform on the ground; lifting lugs are provided on the sides of the housing for raising the regulator to the platform. As they are not intended for suspension from cross-arms, they are not provided with mounting tugs.

FIELD RHEOSTATS

Rheostat.—For regulating the current in the shunt fields or separately excited fields of A.C. and D.C. generators and motors, it is customary to use field rheostats made up of faceplates and resistors of suitable design. The faceplate comprises a series of contacts, usually 20, 24, 40, 48 or 60, arranged in a circle mounted on a slate or marble base and provided with a movable contact arm. Stops on the faceplate limit the travel of the contact arm which is usually of the flat lever type up to 75 amperes and finger contact for larger, and is mounted on a shaft and operated either by a handwheel placed directly on the shaft or operated from a distance through sprocket and chain, bevel gears, solenoids or motors. With small A.C. generators having their own exciters, concentric handwheels, shafts and operating mechanisms are frequently provided for the generator and exciters

Distant Control.—There are various advantages to be obtained by mounting the rheostat at a distance from the switchboard, the main ones being the removal of the heat producing resistors from the immediate neighborhood of the switchboard and the possibility of placing the faceplate close to the resistors. In moderate capacity plants, sprocket-chain and wire-rope transmission is customarily employed for connecting together the handwheel on the switchboard and the faceplate near the resistors and their relative location can be made to suit the station requirements.

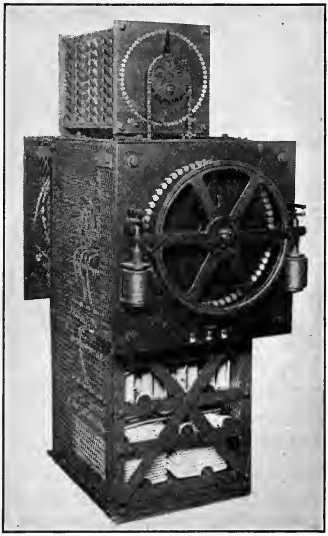


Fig. 154.—Solenoid operated field rheostat.

In very large stations where electrical operation is applied to the oil circuit breakers, the field rheostat faceplates are usually made solenoid operated in the smaller sizes and motor operated in the larger.

Solenoid Control.—Fig. 154 shows a typical arrangement of a 48-step solenoid operated faceplate mounted on grid resistors. The operating mechanism and contacts are covered by an iron shield, sufficient space being left to allow for inspection, and a handwheel being provided for hand operation. The solenoid mechanism consists of two electro magnets, a ratchet wheel, two pawls, a make and break switch and the necessary levers and springs.

Motor Control.—For larger capacities a motor operated faceplate, such as shown in Fig. 155, is employed. This type of face plate is provided with a clutch so that in case of trouble to the motor, the faceplate may be operated by hand, after disengaging the clutch. With this faceplate a signal switch is provided to light up a lamp on the switchboard when the contact arm is bridging two contacts. This faceplate is also provided with limit switches that open up the control circuit when the contact arm has reached the limit of its travel in either direction. The connections are so made that while the rheostat can no longer be operated in one direction it can be operated in the other.

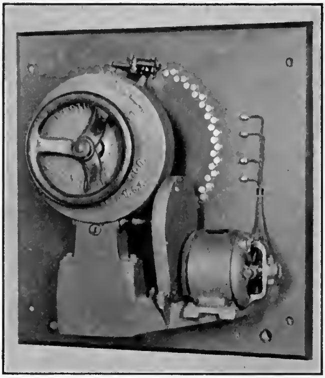


Fig. 155.—Motor operated field rheostat face plate.

Resistors.—Modern rheostat resistors are usually either of the bar form or the grid form. The bar form consists essentially of an iron bar covered with a suitable insulation and wound over with a wire of varying sizes so that with a bar 1 inch by 1/8 inch in section, the resistance per linear inch of bar can be varied from 0.03 to 400 ohms, with a maximum capacity of 4 watts per linear inch.

Grids.—For heavier capacities grid resistors are employed, these being made of cast iron of considerable mechanical strength and high thermal capacity. These grids are cast in various shapes to secure the desired resistance and are assembled on insulated rods and clamped together, being connected in series or multiple as required.

GENERATOR REGULATORS

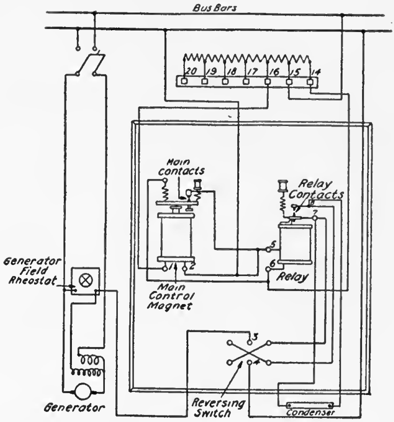
Generator Regulation.—The earliest plants with poorly regulating generators were only able to maintain proper voltage by depending on the switchboard operator to continually adjust the voltage by means of the rheostat. To reduce the amount of adjusting, generators were made with very good inherent regulation and various schemes were developed to get the equivalent of a compound winding on an A.C. generator. These generators with close inherent regulation were expensive to build and their windings were difficult to brace against the effects of short circuits so the trend of generator design turned to generators with high reactance and poor inherent regulation, as soon as a satisfactory regulator had been developed for maintaining the A.C. voltage at its proper value under conditions of varying load.

Tirrill Regulators.—In order to maintain practically constant voltage on A.C. and D.C. generators, or to have those machines compound automatically to take care of feeder drop, field regulators of various kinds have been designed, the best known being the Tirrill.

While Mr. Tirrill has been connected at one time with the General Electric Company and later with the Westinghouse Electric & Manufacturing Company working on regulator designs, he has not been with either company for a number of years, and many of the features of the regulators were due to the ideas of other engineers at these two companies. His name has been so closely connected with the development of this type of voltage regulators that most engineers not connected with the two manufacturing companies are still apt to speak of the regulators as a "G. E. Tirrill" or a "Westinghouse Tirrill" although neither company uses the name "Tirrill" in describing their regulators.

A.C. Regulators.—The various uses to which alternating-current voltage regulators are best adapted fall into the following divisions: (*a*) the maintenance of constant voltage at generator, bus, or some predetermined center of distribution; (*b*) the maintenance of constant voltage at the end of transmission lines by the control of synchronous condensers or synchronous boosters; (*c*) the control of booster-type rotaries; (*d*) the control by special regulators of synchronous condensers applied to local network or distributing systems for voltage regulation and power factor correction; and (*e*) the maintenance of constant current instead of constant voltage.

D.C. Regulator—G. E. Type.—For direct-current service the G. E. regulator consists essentially of a main control magnet with two independent windings and a differentially wound relay magnet with connections about as shown in Fig. 156. The potential winding of the main control magnet is connected across the generator terminals and the other winding across a shunt in one of the load mains. This opposes the action of the potential winding and makes the generator over compound for line drop. The main features of the diagram are self evident. When the effect of the potential winding diminishes, due to drop in volt-



Regulator	Range of Voltage 16	17	18	19	20
TD-125	105	110	115	120	125
TD-250	210	220	230	240	250
TD-550	550				

FIG. 156.—G. E. voltage regulator for D.C. machines.

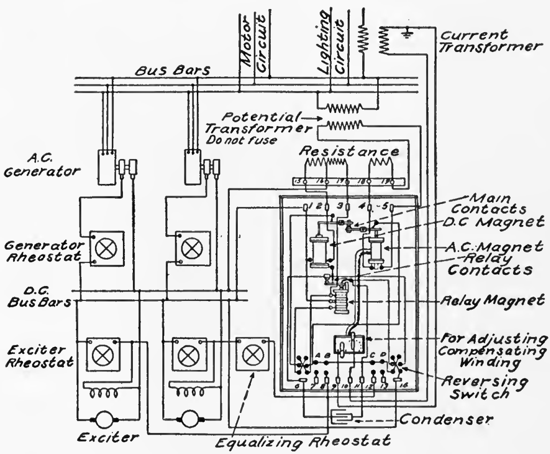


FIG. 157.—G. E. voltage regulator for A.C. machines.

age or increase in load, the spring lifts the main contact which in turn energizes the relay magnet closing the relay contact, thus short-circuiting the generator rheostat and raising the voltage. The relay contacts are shunted by a condenser to reduce the sparking.

A.C. Regulator—G. E. Type.—With A.C. generators, that are almost invariably separately excited, the G. E. regulator works on the exciter field as shown in the simplified diagram of connections in Fig. 157. The main contacts with this type of regulator are acted on by two sets of control magnets, one connected across the exciter bus and tending to move the main contacts further apart as the exciter voltage rises while the other control magnet is acted on by an A.C. potential coil and current coil while suitable springs and counter weights allow the proper adjustments to be made. When the main contact closes it energizes the relay magnet, closing the relay contact, short-circuiting the exciter rheostat and raising the exciter voltage and consequently the generator voltage.

Compensation.—As may be noticed from the diagram the compensating winding is provided with a dial switch to give any amount of compensation required for the feeder circuit in which the current transformer is located. Where it is desired to compensate for both ohmic and inductive drop under varying power factors a special compensator is provided. A modification of the regulator to take care of larger exciters has a plurality of relay contacts, all operated at the same time from the one set of control contacts, the various relay contacts being shunted by condensers to reduce the sparking.

D.C. Control.—The features of the G. E. regulator, that have been so conducive to its successful operation, are the method of control adopted and the fact that with the total range of regulation from no-load to full-load the maximum travel of the only moving parts, the vibrating contacts, is only $\frac{1}{32}$ inch. The vibrations are so rapid that the time factor is reduced to the minimum possible limit and there are no retarding effects due to dashpots or other damping devices. The use of the exciter voltage as one of the main control circuits also prevents overshooting for, as the exciter voltage rises to bring up the A.C. voltage, the D.C. control tends to keep the main contacts apart and so reduce the voltage again.

Westinghouse.—Westinghouse voltage regulators, arranged in a suitable case, are constructed for bracket, panel, or pedestal mounting, as required by installation conditions. Bracket mounted regulators are provided with a standard black-marine slate base.

The regulator parts as shown in Fig. 158 are arranged in the case with the control system located in the upper part supported on a small cast base, and with the rheostat shunting relays arranged in horizontal rows at the bottom. The control element and relays are self-contained units and either may be removed from the base without disturbing its adjustment.

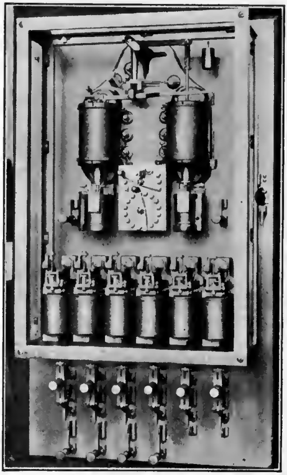


Fig. 158.—Westinghouse automatic generator voltage regulator.

Control.—The control system for alternating-current and separately excited direct-current generators consists of the main control magnet and the vibrating magnet, with the main contacts between them. The magnets are of the solenoid type, and are very sensitive. They are provided with adjustable dashpots to permit adjustment of regulation to suit the characteristics of the system.

Vibrating Relay.—One of the relays, called the vibrating magnet relay, is used to govern the operation of the vibrating magnet. On the larger size generators, one or more master relays are used to control a group of rheostat shunting relays, thus relieving the main contacts of handling control circuits beyond their capacity.

Master Relay.—The use of the master relay is made possible by the alternating-current control and permits of the construction of regulators with as many as 60-rheostat shunting relays. The master relay introduces no time lag in the response of the regulator, nor in the voltage regulation, since the vibrating magnet relay and the rheostat shunting relays operate simultaneously.

Action.—Referring to Fig. 159 the main control magnet has its core attracted upward. Its core stem is connected to the floating lever, which is pivoted to the bell-crank lever of the vibrating magnet. A counterweight is used to assist the pull of the main control magnet, and to bring the lever and core to a balanced position at the normal voltage to be regulated. The vibrating magnet also has its core attracted upward. Its core stem is connected to one end of the bell-crank lever which is pivoted to the base, and its opposite end carries the floating lever of the main control magnet. The pull of this vibrating

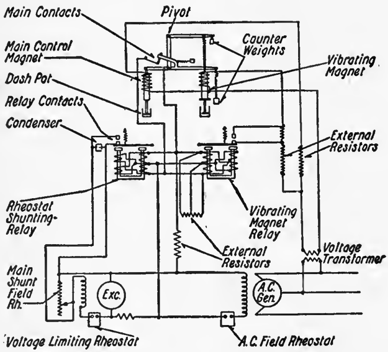


Fig. 159.—Westinghouse voltage regulator diagram.

magnet is assisted by a single spring as shown. These two magnets are energized from the same voltage transformer, and actuate the movable main contact into and out of engagement with the fixed contact.

Diagram.—An inspection of the schematic diagram shows that the closure of the main contacts causes all relay contacts to close. One of the relays, called the vibrating relay, is connected so that the closure of its contacts shunts a small portion of the resistance in series with the vibrating magnet, thus increasing its pull and opening the main contacts. The opening of the main contacts open all relay contacts and inserts the full resistance in the vibrating magnet circuit, weakening the pull and closing the main contacts again.

From the above cycle, it is seen that for any given position of the floating lever, a condition of continuous vibration results.

A necessary condition to the continuous vibration of the system is that the weight of the vibrating magnet core and lever must be exactly balanced by the tension of the control spring and average pull of the magnet. Any change in the tension of the control spring results in an equal change in the average magnet pull. For a given line voltage there is a definite magnet pull when the contacts are closed, and a definite pull of less value when the contacts are opened. The average magnet pull must be a function of the time of the contact engagement. For any given position of the floating lever, there is a corresponding position of the bell-crank lever and tension of the control spring. However, on account of the balanced condition there must be a corresponding average magnet pull and time of contact engagement.

Rheostat Shunting Relays.—The contacts of these relays open and close across the shunt field rheostat of the exciter, and the effective resistance of the rheostat is determined by the time of contact engagement. For any effective resistance, there is a corresponding exciter voltage, and, therefore, A.C. voltage.

A.C. Control.—As the control element is energized from the A.C. generator the main control magnet will assume a position such that a time of contact engagement is maintained sufficient to develop an exciter voltage and, therefore, an A.C. voltage capable of balancing the core weight. Any variation in line voltage changes the position of the floating lever in such a manner as to vary the excitation and restore the balance.

There are many interesting features such as the equalizing rheostats used with two or more exciters, the overvoltage relays to guard against trouble from excessive rise of voltage if a contact should stick which cannot be more than mentioned in this place.

For further details regarding the methods of operation, the cutting of the regulator into and out of service, the securing of line drop compensation, the parallel operation of voltage regulators, reference should be had to the manufacturers' catalogues, instruction books and similar publications.

Application.—The successful application of voltage regulators depends on several factors entirely independent of the size and design of the regulator itself. It is not only necessary that the regulator be properly designed, but it is also essential that the exciters, generators, and prime movers possess characteristics that will harmonize with each other and will assist in keeping the voltage at the desired value under rapidly changing load conditions. In general, the following conditions should be approached as nearly as possible in order to obtain satisfactory reults:

1. Prime movers must be provided with proper automatic governors that will respond instantly to changes in load and keep the speed reasonably constant (within 3 percent to 4 percent from no-load to full-load).

2. Alternating-current generators should have as nearly as possible the same percentage range of excitation from no-load to full-load.

3. Exciters must be capable of delivering sufficient voltage to take care of the alternating current generator fields under full-load conditions, 80 per cent. power factor, plus a certain additional voltage. This additional voltage above the steady exciter voltage required to maintain constant bus voltage under full-load conditions, is necessary in order that the regulator will continue to vibrate and thereby have control of the exciter.

4. Exciters (where more than one are to be considered) must be adjusted to operate in parallel under all loads and at any point of the saturation curve.

5. Exciters for 125-volt service should be able to build their voltage up or down between the limits of 30 and 125 volts in 5 seconds or less under load consisting of generator field circuits. The time constant should be the same for exciters of other rated voltages over proportional ranges. Exciters with greater time constants than this may not permit the regulator to maintain constant voltage with rapidly fluctuating load.

6. 125-volt interpole exciters must be able to develop at least 135 volts with the series winding disconnected, and should be so operated. The series winding must be cut out of circuit in order to secure a satisfactory time constant. In general, the exciter must be capable of developing a voltage 10 to 15 per cent. in excess of that required by the A.C. generator at full-load, 80 per cent. power factor, the A.C. generator field rheostat being adjusted so that with 60 volts on a 125-volt exciter the A.C. generator develops normal voltage at no-load.

Flicker.—On small systems, supplying a mixed lighting-and-power load, where induction motors are sometimes thrown directly on the line without starting devices, the momentary current required may be of such a value as to affect the feeder system and cause a noticeable flicker in the lights. Automatic regulating devices in the generating station cannot be made sensitive enough to prevent this effect under such conditions.

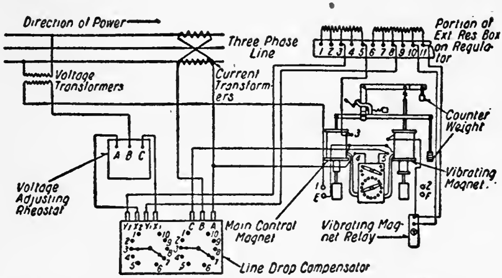
Voltage Adjusting Rheostats.—Taps are always provided on the external resistor whereby the voltage regulated can be varied from 104 volts secondary to 116, in steps of 6 volts. Where, for any reason it is desired to vary the operating voltage of the system from time to time, a voltage adjusting rheostat should be used in the control element circuits for the fine adjustment of voltage, instead of varying the counterweight. This rheostat has a sufficient resistance to give an adjustment of about 6 volts either way from the normal voltage when properly applied. The use of this rheostat is recommended in all applications, as it is a much more convenient and satisfactory method of adjusting the voltage while the regulator is in operation.

Single Operation of Exciters and Parallel Operation of Generators.—By the use of a control element energized entirely from the A.C. system, the operation of alternating-current generators in parallel with the exciters operating singly, has been made possible. The regulators for such service are equipped with special transfer switches so that the D.C. circuit for energizing the relays may be transferred to any exciter that may be in operation.

Compensation.—For complete line drop compensation, it is necessary to consider two factors, namely, inductive drop and ohmic drop in the line and transformers between the generator bus and the distributing center. The inductive component of line drop is at right angles to the load current and is compensated for by introducing into the potential circuits of the regulator a voltage in phase with and proportional to the actual inductive drop. An external compensator, energized from series transformers, properly connected, accomplishes this purpose. This compensator is provided with adjustable dials by means of which the voltage introduced in the regulator circuits, for a given ampere load, may be varied, thus permitting adjustment for the percentage inductive load.

The ohmic component of line drop is in phase with the load current and is compensated for by energizing the current windings of the regulator coils from series transformers properly connected. The regulator control magnets are then affected by a magnetizing force which is in phase with the load current.

The current windings on the regulator coils are divided into sections and connected to an adjustable dial. This provides a ready means of obtaining the proper percentage of ohmic compensation. Fig. 160 shows the connections to 3-phase systems for this method.



The above connections are correct for a secondary operating voltage of 110 Volts. If a different operating voltage is required, refer to the diagram of connections furnished with the Voltage Adjusting Rheostat for the proper connections to the external resistor

FIG. 160.—Compensator connections for regulator.

To obtain complete line drop compensation it is necessary to adjust both the compensating devices to agree with the line characteristics. Where ohmic line drop compensation only is desired no external compensator is necessary. The current windings on the regulator coils, when properly energized from series transformers, accomplish this result. For 3-phase systems, two current transformers in vector parallel are required for complete compensation. The transformers must be in the same legs of the circuit as those to which the voltage transformer is connected in order that the resultant current will be in phase with the voltage at 100 per cent. power factor.

Parallel Stations.—Where stations operate in parallel, and each is controlled by a voltage regulator, it is possible to compensate for the ohmic drop only, as inductive compensation destroys the stability of the system. The point in the system at which it is desired to maintain constant voltage should be determined in order to obtain proper compensation.

Condensers.—These are required for connection across the rheostat shunting relays, to minimize the contact wear occasioned by the sparking incident to the opening of the shunt across the exciter field rheostats.

Exciter Rheostats.—When a regulator equipment is being added to a plant in operation, the existing exciter rheostats should be checked to determine whether they have sufficient resistance to permit of adjusting the exciter for the proper time constant. If not, new exciter rheostats must be provided. If the shunt field rheostat of the exciter used for hand control is unsuitable for use with the regulator, it can in many cases be used as the voltage-limiting rheostat.

Auxiliary Exciter Rheostats.—Where two or more exciters, operating either singly or in parallel, are controlled from a regulator, the use of an auxiliary rheostat is required in the field circuits of each exciter to adjust the time constants and maximum voltage of all the exciters to the same values in order that they will carry their proper share of load. Where only one exciter is controlled by a regulator the use of an auxiliary rheostat is not required unless too high a maximum voltage and, consequently, too large a field current, is obtained when the main exciter rheostat is short-circuited by the relay contacts.

Voltage Transformers.—These of 400 volt ampere capacity with fuse blocks and fuses are required for all alternating-current voltage regulators.

Current Transformers are required only when compensation for line drop in some particular circuit is desired, or when two or more regulators are operating in parallel. One current transformer is required for partial compensation or two for full compensation, and one transformer is necessary for each regulator where two or more regulators operate in parallel. No current transformer is necessary when it is desired to maintain constant bus voltage.

Voltage Rise.—With the ordinary type of generator voltage regulator, when a short circuit on a system is cleared away, a dangerous voltage rise is inevitable. On the occurrence of a short circuit on a system without some protective device, the main contacts of the regulator close, causing the relay contacts to close and the exciter voltage to build up to the maximum value. When the short is cleared away, a high voltage results, due to the high exciter voltage and consequent high generator field current, which lasts until the regulator has had time to again become operative.

Excess Voltage Device.—This condition of excessive voltage can be prevented by means of the excess voltage protective device, which can be applied to any Westinghouse A.C. regulator. A diagrammatic view of this device is shown in Fig. 161. It consists of an undervoltage relay in combination with a direct-current control element connected in the main contact circuit of the alternating-current voltage regulator. The contacts of the D.C. element and the relay are connected in parallel, the pair being in series with the main contacts of the regulator. The D.C. element is energized from the exciter bus, and the relay from the potential transformer supplying the A.C. regulator.

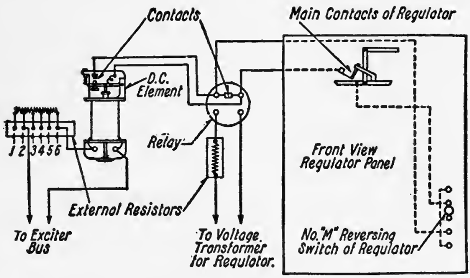


FIG. 161.—Excess voltage protection for regulator.

A short circuit coming on a system equipped with this protective device immediately causes the main contacts of the regulator to close and the A.C. relay contacts to open, on account of the drop in the A.C. voltage. As soon as the exciter voltage builds up to the point for which the D.C. element is adjusted, the contacts of this element begin to operate and to regulate the exciter voltage in the same manner that the regulator contacts normally do, so that the exciter voltage can never rise above the predetermined point, which is usually a little above the no-load excitation value required by the A.C. generators. When the short circuit is relieved, therefore, no excessive field current exists to produce a dangerous rise in A.C. voltage. The moment the A.C. voltage rises above the setting of the undervoltage relay, the contacts of the relay close and put the A.C. voltage regulator back into service.

Battery Control.—Where storage batteries are used in a power plant it is ordinarily necessary to provide some means of keeping a fairly constant voltage on the D.C., bus bars or constant load on the generators independent of the condition of charge of the battery or load on the feeder circuits. As the usual lead cell when fully charged has a voltage of 2.5 per cell and as it is safe to discharge a battery down to about 1.75 volts per cell it is evident that some means must be provided to take care of this range of voltage.

While end cell switches are used to a certain extent, the end cells are only in service part of the time and do not get the same service as the rest of the battery. In order to work all of the cells the same amount it is customary to install a booster whose voltage added to or taken from that of the battery will give the desired pressure on the bus bars. Without going deeply into the design of the battery or the booster it may suffice to say that boosters usually have their armatures connected in series with the battery across the bus while the field circuit on the booster may be series, shunt or separately excited.

In order to avoid the necessity of hand regulation of the booster voltage many very ingenious regulating schemes have been devised and regulators make these schemes effective and enable the voltage of the booster to automatically change in direction and amount so as to enable the battery to charge, discharge or float on the line.

CHAPTER X

INDUSTRIAL CONTROL APPARATUS

While it is not the intention of this book to go deeply into the question of industrial control apparatus these devices are so frequently used in connection with other switching equipment for the control of the automatic substations or of motors in a power plant that it is necessary to give some short descriptions of some of the devices most frequently used in connection with the other switch gear devices.

It is difficult to draw a very definite line in some cases between control apparatus and switching equipment for power control but the former may be considered primarily as intended for motor control while the latter is used for power plants and general distribution. Control apparatus is designed for severe service and very adverse conditions and ruggedness is its essential characteristic, with appearance considered usually of minor importance.

Apparatus.—Some of the devices such as contactors, controllers, starters, etc. will be considered in a rather brief fashion as a full discussion would go beyond the province of this book and should be reserved for a book dealing particularly with that subject.

Contactors.—Contactor switches or contactors might be described as switches or circuit breakers requiring some auxiliary source of power, such as a solenoid or compressed air to hold them in the closed position. They are used principally for motor control and are designed primarily for multiple unit control of railway motors and automatic or semi-automatic control of industrial motors. These contactors are made in many forms by different companies and except for the electro-pneumatic system of multiple unit train control are usually made solenoid operated and frequently provided with magnetic blowout attachments.

Typical Design.—In the design illustrated in Fig. 162 the contactors are built in sizes up to 1250 amperes D.C. and they consist essentially of a contact that is closed by the action of a solenoid which raises its plunger vertically when the coil is energized and allows it to drop back by gravity assisted by springs when the coil is de-energized. The main contacts are above the solenoid and are protected by magnetic blowout coils which are so placed on each side of the main contact that the arc is forced quickly to the front and blown out. In this design the main contacts are of the butt type, the lower portion being moved by the plunger and the upper portion being fixed either rigidly or with a slight spring motion. The main contacts in the larger sizes are double, the arcing tips being made of brass and being readily renewable and the other contacts being of copper.

Fig. 162.—Contactor switch.

Interlock Contacts.—These contacts located below the solenoids consist of flat brass discs carried on an insulating rod attached to the lower end of the plunger rod, these rings making contact against copper blocks attached at the outer ends of insulating supports hung down from the contactor. These interlocking contacts carry only the small amount of current required for the magnet coil. These contacts can be readily arranged to secure practically any scheme of electrical interlocking that may be desired and to insure the closing of a series of contactors in any predetermined sequence.

Master Switch.—These contactors are ordinarily used in connection with a master switch or controller and protective relay switches of various kinds to insure the performance of various functions, such as the automatic cutting in and out of resistance in the secondary of an induction motor; to maintain constant input to a flywheel set; or any similar features that may be desired.

Controller.—A controller may be described as a switching device, usually with a movable arm or drum, that makes various connections in a predetermined manner for the purpose of starting one or more motors and regulating their speed, output or other characteristics.

Functions.—Controllers are designed to be used with motors of different kinds and to take care of the functions not incorporated in the motor design in order to enable the latter to operate under the specified conditions of load. The functions usually supplied by the controllers are the following:

To limit the current during the acceleration of the motor.
To limit the torque during acceleration.
To change the direction of rotation of the motor.
To limit the load on the motor.
To disconnect the motor on failure of voltage.
To regulate the speed of rotation.
To start and stop the motor at fixed points, on the cycle of operation, or at the limit of travel of the load.
To stop the motor.
To protect the operator from injury.

Not every controller has to embody all of these features in the same degree but these are the underlying points of controller design and they must be procurable when they are needed.

Faceplate Controller.—The simplest form of controller for starting and regulating the speed of the D.C. motor is the faceplate type shown diagrammatically in Fig. 163, and intended for use with a variable speed motor connecting resistors in the armature and field circuit. With this type of controller the contacts are mounted on the face of a suitable slab and a moving arm makes the connections to the armature and field circuits, the speed of the motor being changed by varying the field strength. The rheostat arm is made in two parts, the under part making contact with the segment of R-1 to R-12 and with the contact ring E, while the top arm engages the upper row of round contacts. When starting, the two arms are held together by a latch. The bottom arm is provided with a notched segment engaging the plunger forming part of the low voltage release magnet. The notch segment and pawl hold the arm in any operating position after the low voltage magnet is energized. To start the motor the contact arms are moved from the off position to contact R-1 and the connections can readily be traced from that point. The arms are gradually moved to the right eliminating successively each section of the armature resistor until the bottom arm makes contact with R-12. In this position the armature is connected directly across the lines and the segment *E* disconnected from the rheostat arm. The shunt field circuit now is from the positive side of the line to the upper rheostat arm to the right hand field contact F-12, thence to the field winding. This gives a motor speed due to full field strength. If it is desired to increase the speed of the motor the upper arm can be moved to the left across the field contacts to insert resistance gradually in the shunt field circuit, and thus, within its range, give the increased speed desired, while the low voltage release magnet holds the lower

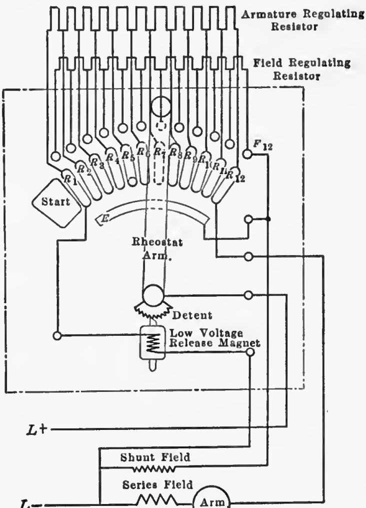


FIG. 163.—Face plate controller.

arm on contact R-12. If the circuit is interrupted the low voltage release magnet will allow the lower arm to be carried to the off position by means of a spring. This in turn picks up the upper arm and the two are moved quickly to the off position.

Drum Controller.—Another type of controller in common use is the drum controller. These are used with machine tools for varying the speed and reversing the direction of rotation of adjustable speed D.C. motors by means of armature and field resistance. On the larger sizes magnetic blowouts are used. The drum controller usually has two rows of contact fingers attached to the frame work of the controller but insulated from it so as to be electrically separated from each other. Between these rows of fingers is mounted an insulated cylinder or drum which is revolved by the handle. On this drum are mounted copper segments of different lengths which engage the contact fingers. The length and location of these segments are such as to make different connections for each position of the controller handle.

Drum controllers are also used as master controllers with contactors of various kinds to secure starting and speed regulation of large A.C. and D.C. motors as well as the multiple unit control of motor cars or locomotives on railway service. The faceplate type of starter with field regulation for D.C. motors may also be considered as a controller

Starting Resistance.—In starting direct-current motors it is usually necessary to insert a resistance in the armature circuit to limit the amount of starting current. As the motor speeds up and its counter E.M.F. increases, this starting resistance is gradually cut out until, when the motor has reached full speed, the resistance is all cut out and the motor armature is connected to the full voltage of the source of supply. These starting rheostats usually have various features; such as no voltage and overload release, sometimes combined with field control and making the starters described in the next few paragraphs.

D.C. Starters.—The starters for use with constant speed D.C. motors consist usually of a resistance to be inserted in the armature circuit to limit the amount of current taken when starting, this resistance being gradually cut out by the movement of a contact arm over a faceplate as the motor comes up to speed. Such rheostats connect the motor field in circuit at the first step and are provided with various safeguards such as low voltage release, etc.

Low Voltage Release.—As a rule the low voltage release consists of a coiled spring around the pivot of the rheostat arm for returning it to the off position, and an electromagnet for retaining the arm in the on position as long as the line voltage continues above a predetermined minimum value. On failure of the line voltage the magnet releases the arm which is at once returned automatically to the off position by the spring.

To guard against drawing an arc when the contact arm leaves the first contact in going to the off position, this contact is usually protected by an arcing tip which provides a spring operated break, or a magnetic blowout is furnished that extinguishes the arc that tends to form.

Typical D.C. Starter.—Fig. 164 shows the connections of a typical D.C. starter with low voltage release. If the rheostat arm is moved from the off position shown in the cut to the contact R-I, current will flow from L plus to the arm; from this to contact R-I through the regulating resistance to R-II; thence through the armature and series field of the motor to L. The shunt field is connected from R-I to L. As the rheostat arm is being moved from R-I to R-II there is a small drop in voltage across the shunt field circuit due to the field current flowing through the starting resistor, but this is so small that it may be neglected and the field can be considered as having full voltage impressed upon it. The rheostat arm is provided with a spring which returns it to the off position and the handle is released during the starting of the motor. After the motor has been brought up to speed and the rheostat arm rests upon contact R-II the low voltage release magnet holds the arm in this position. Brush 'B' bridges between the terminals 'M' and 'N' so that in the running position the current passes from L plus to terminal 'M,' through the brush 'B' to the terminal 'N,' thence to the armature of the motor through the series field to L-I.

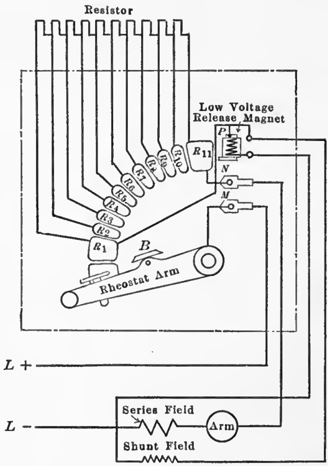


Fig. 164.—D.C. starter with low voltage release.

Multiple Switch Starter.—With the larger D.C. motors where the starting conditions are severe the face type of starter is not found satisfactory, so recourse is had to multiple switch starters, drum controllers, or contactors. Multiple switch starters consist essentially of a number of switches mounted on a panel and a separate resistance usually of cast-iron grids. The switches are mechanically interlocked so that it is necessary to close them in sequence.

Electrically Operated Starter.—In addition to the hand operated starters, motor starters or controllers with electrically operated switches or contactors are available for almost every conceivable service. They can be arranged to start, stop or reverse the motor manually at the will of the operator or automatically at fixed limits and can be set to regulate and adjust the speed. Arrangements can be made to have the motor automatically perform a predetermined series of operations and the control can be exercised from a point near the motor or from a more distant point more convenient for the operator.

Starting Time.—In starting a motor a considerable amount of energy is required to overcome the inertia of the motor and the apparatus it is driving and a considerable amount of time is required to bring the motor from a state of rest up to full speed. To avoid wrecking the motor this energy must be admitted gradually and resistance in the armature circuit is used for this purpose. This resistance designed solely for starting purposes is proportioned to carry the motor current only during the short time necessary to bring the motor up to full speed. If the time taken in starting is too long the resistance may be injured by overheating while if too short the motor may be damaged or the supply circuits seriously disturbed.

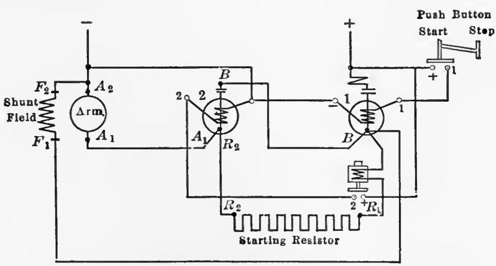


Fig. 165.—Automatic acceleration with series relay.

Automatic Starting.—For these reasons a motor starter that will automatically take care of the proper rate of acceleration presents many advantages and such a starter can be devised by means of contactor switches and suitable relays which are operated either by the variation of the voltage drop across a resistance as the motor speeds up, or by the decrease in current which permits a coil to drop its core as shown in Fig. 165, where acceleration is controlled by a series relay. This is satisfactory where the voltage does not vary more than 12½ per cent. either way from a constant value. Fig. 165 shows the connections of a shunt motor controlled by means of two contactor switches, a push-button switch, and a series relay. When the push button is closed in the starting position, the coil of contactor No. 1 is energized, closing the contactor and completing the circuit through the series relay, the starting resistor, and the armature of the motor. When the starting current has dropped to a certain value the current in the series relay is no longer sufficient to hold open the contacts so that connection is automatically made to the operating coil of contactor No. 2 closing that contactor and short-circuiting the starting resistors. With very large motors several contactors with series relays are provided.

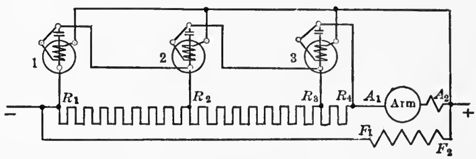


FIG. 166.—Automatic acceleration from counter E.M.F.

Counter E.M.F.—When a motor is started from rest and accelerated to full speed, the voltage across the motor terminals increases as the speed of the motor increases. If the coil of a magnetic contactor is connected across the motor brushes the current in this coil will increase as the speed of the motor increases. Fig. 166 shows a starting arrangement based on the counter E.M.F. method and it may be noted that the operating coils of the three contactors have one side connected to the motor brush farthest away from the starting resistor. The other sides of the operating coils are connected to the taps on the starting resistor, the coil on switch No. 1 being connected to R-2 on the resistor. The voltage on this coil is equal to the line voltage less the drop in voltage through the first section of the resistance. As the speed of the motor increases the counter E.M.F. causes decrease in the armature current. This reduces the drop to the first section of the starting resistance. The voltage on the operating coil of switch No. 1 is gradually increased until this switch closes. Switch No. 2 has its operating coil connected to R-3 on the starting resistor. The voltage on this coil is increased by the closure of switch No. 1. The increase in current causes a considerable drop in the second section of the starting resistance. As this current gradually decreases due to the increased speed of the motor, switch No. 2 closes. Switch No. 3 is connected across the motor armature and closes when the counter E.M.F. of the motor is nearly equal to the line voltage. The main contactors for closing the main + and − circuits are not shown in the diagram.

Series Lockout.—Another scheme of acceleration frequently used is the series lockout method. With this arrangement the magnetic contactor is provided with a series coil and does not require a separate relay for controlling it. The closing of the magnetic contactor depends upon the saturation of the iron in one portion of the magnetic circuit. This can be understood from the diagram of a contactor of this design shown in Fig. 167. The flux or magnetism in the iron is caused by the current flowing through the operating coil. This flux passes through the air gaps in the armature of the contactors. Part of this flux passes from the armature through the armature brackets to the magnetic yoke and thence to the magnet core. Another part of the flux passes from the armature through the tailpiece of the magnet yoke. The flux through this last circuit exerts a pull which prevents the contactor from closing. The magnetic path through the armature brackets is of small cross-section so that when the current flowing through the operating coil exceeds a certain value it becomes saturated and forces the balance of the flux through the tailpiece holding the contactor open. As the current decreases, the flux in the saturated armature bracket remains constant and the flux through the tailpiece decreases until it is not sufficient to hold the contactor open. The switch can be adjusted to close at a predetermined value by changing the

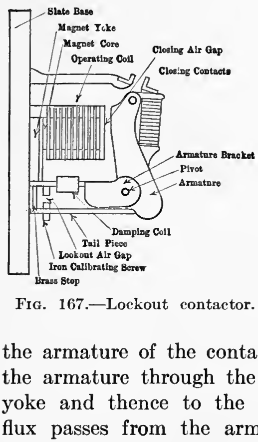


FIG. 167.—Lockout contactor.

hold out air gaps between the tailpiece and the magnet yoke by means of a calibrating screw.

Lockout Contactor.—The success of starters with acceleration control such as previously described, depends largely on the contactors or contactor switches. Contactors are switches or circuit breakers which are held in the closed position by some auxiliary power such as a solenoid or compressed air. A typical contactor is very similar to the lockout contactor shown in Fig. 167, using a shunt coil instead of the series coil and omitting the tail piece, the damping coil and similar features, so that as soon as the shunt coil is energized the contactor is closed against the pressure of a spring. Contactors are built both for D.C. and A.C. operation and are made single pole and multipole, single throw and double throw, in various capacities. The main arcing contacts are usually protected by means of a magnetic blowout.

These contactors are ordinarily used in connection with a master switch or controller and protective relay switches of various kinds to insure the performance of various functions, such as the automatic cutting in and out of resistance in the secondary of an induction motor to maintain constant input to a flywheel set or any similar feature that may be desired.

A.C. Starters.—Starters for A.C. motors may be divided into two classes; those used with motors having a squirrel-cage or short-circuited secondary and those for motors having a wound secondary. In the former case the starting is done by impressing on the primary a voltage sufficient to induce in the short-circuited secondary the current required to develop the proper starting torque, and then transferring the primary connections to full voltage.

Wound Rotor Motors.—With motors having a wound secondary it is customary to connect the primary to full voltage at starting with the secondary short-circuited through a resistance. As the motor speeds up this secondary resistance is cut out in one or more steps until at full speed the secondary is short-circuited.

Squirrel-cage Motor.—With squirrel-cage motors up to about 7½ H.P. it is usually feasible to connect the primary immediately to the full line voltage without drawing an abnormal current from the line.

For textile work where small motors are used in large numbers on circuits up to 550 volts, a special oil immersed switch is used, this being made single throw for ordinary service, double throw when reversing is wanted.

Auto Transformer Starting.—Under normal conditions the most satisfactory means of obtaining the reduced voltage for starting induction motors with squirrel-cage secondaries is by the use of auto transformers, the connections for this method of starting being shown diagrammatically in Fig. 168, the switching

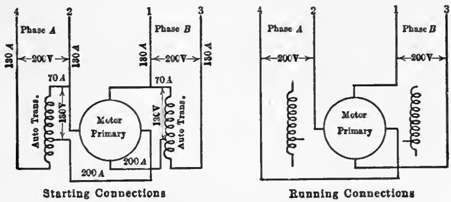


FIG. 168.—Auto-starter connections.

mechanism being omitted for the sake of simplicity. In the starting position the voltage at the motor primary which is connected to the auto transformer is cut down by the auto transformers from 200 to 130 in this particular case. The current in the motor primary is 200 amperes but the line current due to the transformer action is only 130 amperes. In the running position the motor primaries are connected directly across the line and the auto transformers are disconnected at one end so that their losses are eliminated.

Starting Voltage.—The starting voltage of induction motors should not be greater than is required for the starting torque; hence the starting voltage should be adjusted to the service conditions. The auto transformers supplied for starting induction motors are provided with taps permitting the choice of any one of several voltages. The auto transformers are designed for starting service only and are not intended to be left permanently in circuit.

Auto Starters.—The auto-starter switches or circuit breakers are made of various types, usually either with wedge contacts or brush contacts depending on the current to be handled. The equivalent of the double-throw switch is usually furnished, one throw energizing auto transformers and connecting the motor to low voltage taps for starting and the second throw connecting the motor directly to full voltage for running. The second throw usually, though not always, completely disconnects the auto transformers from the circuit.

Automatic Protection.—With auto starters this is usually secured by means of overload trip coils, either connected directly in the circuit or operated from current transformers. Usually the overload protection is only in the running position. With certain types of auto-starter switches the overload release device consists of two solenoids with plungers in two different phases and an oil filled dashpot on each solenoid plunger gives an inverse time element feature. The switch contacts usually trip independently of the handle so that the switch cannot be held closed on an overload.

Automatic Starting.—By certain modifications these auto starters can be made suitable for automatically starting and stopping induction motors that are used for driving pumps or compressors so that the level of liquids in reservoirs or the pressures in a compressed air system can be maintained within predetermined limits without supervision. The float type auto starter is applicable to motor driven pumps that supply cisterns and reservoirs, sumps, sewers, etc., if the pump is near enough so that the rising and falling of a float in the reservoir or sump may be communicated by rope drive to a weight device that operates the auto starter.

With the pressure type regulator a pressure gauge switch and relay are supplied that work in connection with an electromagnetically operated valve, two cylinders and a spring and ratchet device to move the auto-starter switch through the starting position to the running position or return it to the off position.

Synchronous Motor.—Where self-starting synchronous motors are used, they are provided with a squirrel-cage winding on the rotor in addition to the usual field poles and field coils and, owing to this squirrel-cage winding, they are started up as induction motors and controlled by the same type of starting devices. Other apparatus such as field rheostats and field switches are necessary to take care of the motor when in the normal running condition.

Phase Wound Motor.—With induction motors having phase-wound secondaries the method of control, as mentioned previously, is to connect the primary circuit directly to the high voltage line with the secondary winding short-circuited through a resistance which is cut out in one or more steps as the motor comes up to speed. The switch or circuit breaker in the primary circuit is made suitable for the voltage and capacity of the motor while the secondary is taken care of by various devices such as drum controllers, butt contact switches, contactors, etc.

Mill Work.—For reversing mill or hoisting work using induction motors with wound secondaries, many very ingenious and highly satisfactory installations have been put in service using solenoid operated magnet switches or contactors for the secondary and occasionally for the primary circuits. These are worked from a master controller or similar device or are operated automatically by the positions of the rolls, hoist, etc. Automatic acceleration can be obtained in the same manner as indicated on Figs. 165 and 166, and various safeguards such as dynamic braking can be employed.

Flywheel Sets.—Another application for contactor control with automatic features is with flywheel motor-generator sets using a very heavy flywheel in connection with a D.C. generator and an A.C. motor with wound secondary. The power put into the flywheel or delivered up by it depends on the variation in speed of the motor generator and by varying the resistance in the motor secondary this speed regulation can be secured. By the use of relays similar to those described, the input to the motor and consequently the load on the A.C. system can be kept practically constant while the output of the D.C. generator supplying power to a D.C. hoist or rolling mill motor is undergoing wide fluctuations, the energy in the flywheel taking care of the difference between the constant input and the variable output.

Automatic Substations.—An application of contactor control of rapidly increasing importance is the automatic substation by means of which rotary converters, motor generators, or other transforming devices are cut into and out of service automatically with the varying demands on the system. Descriptions of these automatic substations are given later.

CHAPTER XI

SWITCHBOARDS—GENERAL INFORMATION

In taking up the question of switchboards, after having devoted many pages of this book to a consideration of the apparatus for power plant control, it should be noted that the term switchboard as here used is applied to the collection of panels, pedestals, posts, control desks, etc., on which are mounted the instruments, relays, switches, circuit breakers, etc. so that from this point of view the switchboard is practically a collection of switching apparatus assembled in a logical manner to facilitate the control of various electrical circuits.

Diagram.—The apparatus previously described can be combined in various ways to secure the results desired in power plant control. These various combinations are usually expressed in the form of a diagram of connections before any attempt is made to decide on the switching equipment.

D.C. Connections.—For direct-current service the main connections usually embody a knife switch and fuses or carbon circuit breakers for securing the automatic protection. In most cases, only a single set of bus bars is employed, and the connections are very simple.

A.C. Connections.—For alternating-current service the connections are usually more complicated, and as the plants are larger and more important, greater flexibility is usually provided.

In making up a preliminary diagram it is usual to show all of the circuits whether direct current, single phase, or polyphase by means of a single line per circuit and to indicate oil circuit breakers, disconnecting switches and similar devices by simple conventional signs.

Single Line Diagram.—In these single line diagrams it is seldom necessary to show the metering and relaying equipment, and usually the diagram is reduced to its simplest elements, merely locating the main generators, transformers, feeders, oil circuit breakers, disconnecting switches, and bus bars.

Typical Connections.—Fig. 169 shows a number of typical connections between generator and bus circuits. On this diagram the generators are represented by large circles, the oil circuit breakers by rectangles, the disconnecting switches by two small circles, transformers by two saw tooth lines, and outgoing feeders by an arrow head. While the main connections are fairly evident from the diagram, the following notes point out some of the principal features.

Fig. 'A' shows a single-bus system with a generator feeding through an oil breaker and a disconnecting switch to a bus; this being about the simplest possible arrangement although occasionally the disconnects are omitted.

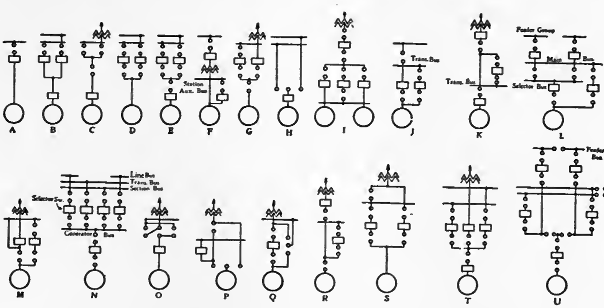


Fig. 169.—Typical connections of generators and bus.

'B' shows a double-bus system with a main breaker, two selector breakers and disconnects for isolating the selector breakers from the two sets of busses. With this arrangement there are two breakers in series between any generator or bus or any feeder or bus, this permitting the testing out of each breaker independently before tying in the circuit. This scheme was a favorite one in the early days of oil circuit-breaker development when complete reliance was not placed on the satisfactory performance of oil breakers. The disconnects permit isolating either selector breaker from the bus, but owing to the absence of any disconnecting switches between the main breaker and the selectors, it is necessary to shut down a circuit before any work can be done on any of the oil breakers.

'E' shows a similar arrangement with the addition of disconnects on each side of the selector breakers as well as disconnects between the generator breaker and the common connection to the two selectors. With this arrangement either of the selector breakers can be completely isolated by means of their disconnects without shutting down the generator or feeder or shutting down the bus. The disconnects between the common connection and the generator breaker are utilized for isolating the generator breaker in case the selectors are to be used for tying together the two sets of busses.

'D' shows a somewhat simpler arrangement with two sets of busses and two selector breakers omitting any main generator breaker. This is a very common arrangement where two sets of busses are desired.

'C' shows a generator with a generator breaker and a certain number of disconnects so arranged that the generator can be connected either to the bus or to the low tension side of a transformer bank or the low tension side of a transformer bank can be connected to the bus, while the generator is shut down.

'F' shows a modification of this arrangement with the generator tied in solidly on the low tension side of its step up transformer with a breaker and disconnects on the high side of the transformer, breaker and disconnects for connecting the machine to the station auxiliary bus.

'G' shows an arrangement very similar to 'C,' but with an additional oil breaker to facilitate connecting the generator to the main bus.

'H' shows an arrangement of a generator with one oil breaker and two sets of disconnects for connecting the machine to either of two sets of busses.

'I' shows two generators feeding through breakers and disconnects to a generator bus. This generator bus in turn connects through breaker and disconnects to the main bus, or through another breaker and disconnects to the low tension side of a transformer bank. With this arrangement the two generators are considered essentially as a single unit and are arranged for feeding their own transformer bank, or tieing to a main bus bar.

'J' is essentially the same arrangement as 'D' except that one bus is considered as the main bus, and the other as a transfer bus for emergency purposes.

'K' shows a combination of one generator and one transformer bank with a total of three breakers and suitable disconnects so that the generator may be connected directly to its own transformer bank or the generator or transformer connected to the transfer bus. A slight modification of this scheme, using the same number of breakers, has one breaker connecting the generator directly to the transformer; a second breaker connecting the generator to the bus, and the third breaker connecting the transformer to the bus, so there are always two paths between the generator and transformers.

'L' shows an arrangement of main bus, selector bus, feeder group busses, etc.

The remaining schemes 'M' to 'U' inclusive, are slightly more complicated, but are all based on the main connections used in actual plants. As practically all of the connections indicated in Fig. 169, can be utilized either for generator or for feeder circuits, they may be considered as forming the elements of diagram construction, and most of the more complicated diagrams are combinations of the various methods indicated.

Instrument Transformers.—After completing the elementary single line diagram, it is frequently a good plan to locate the current and the potential transformers needed for the operation of instruments and relays, and then to prepare a detail diagram showing the interconnections of these various features.

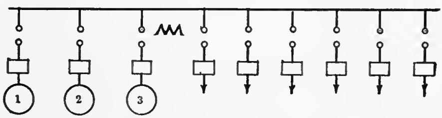


Fig. 170.—Diagram of single bus system.

Single Bus.—For simple plants where economy is of prime importance, the straight single-bus system as indicated in Fig. 170, is usually adopted. This diagram shows 3 generators and six outgoing feeders, each circuit being provided with an oil circuit breaker and a disconnecting switch, and the current transformers being located in such a position as to carry the combined output of all the generators. With a single-bus system such as shown, bus bar trouble, which is very infrequent, necessitates complete shut-down. To replace the oil, inspect or adjust any circuit breaker, it is necessary to shut down the particular circuit involved, but it is not necessary to shut down the entire plant, as disconnecting switches are provided for isolating the breaker from the bus. A still cheaper and simpler arrangement adopted for small boards, dispenses with the disconnects, but this makes it necessary not only to shut down a particular circuit, but also the entire plant, unless the voltage is so low that the repair man is willing to risk working on the breaker while the bus is alive.

Double Bus.—By adopting a double-bus system of one breaker and two disconnects per circuit, one bus can be shut down for inspection of the board or insulators without shutting down any circuit by opening all of the disconnects tied on to that bus. If any particular feeder is giving trouble due to grounds or frequent short circuit, it may be connected to one bus with one generator, and the rest of the plant connected to the other bus. By using

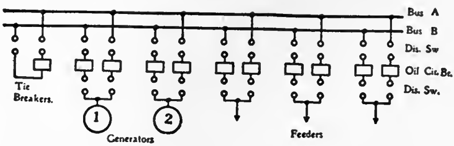


FIG. 171.—Diagram of double bus system.

the double-bus system, with two breakers per circuit, any breaker can be cut out of service for inspection or repair without shutting down a circuit or without shutting down either bus provided suitable disconnects are employed. A bus can also be shut down at any time to have insulators cleaned or connections altered. A typical arrangement employing the double-bus, double circuit-breaker system is shown in Fig. 171, this showing two generators, three outgoing feeders and a bus tie breaker. In many systems employing the double-bus and double circuit-breaker equipment, the breakers are interlocked so that normally a circuit can only be connected to one bus at a time. The tie breaker is used for connecting the two busses together, and provision is made for synchronizing around the tie breaker. In any case, however, where it is desirable to be able to transfer a generator or feeder from one bus to the other without opening the circuit, the breakers are not interlocked. In this case, the tie breaker is dispensed with and when it is desired to tie the two busses together, two of the generator breakers or feeder breakers are connected in at the same time.

Ring Bus.—Where stations of moderate size require great flexibility and maximum security and where due to the low voltage employed, the current in the bus is apt to be excessive unless limited to the full output of one machine, the arrangement shown in Fig. 172 is adopted. With this arrangement, each generator and feeder is provided with a breaker and the equivalent of double throw disconnects. The busses are practically divided into four sections which sections can be tied together to form a complete ring bus.

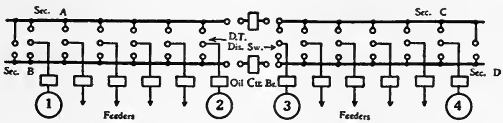


FIG. 172.—Diagram of ring bus system.

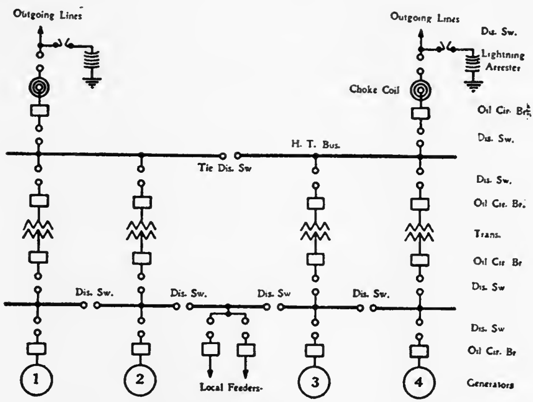


FIG. 173.—Diagram of typical plant with sectioned bus.

Sectioned Bus.—Fig. 173 shows a plant controlling four generators, four step-up transformer banks and two outgoing lines using the single sectionalized bus system. Each circuit is provided with one breaker and one set of disconnects, but the busses are so sectionalized, that normally each generator will tie in with its own transformer bank, and two transformer banks will normally supply current to their own outgoing line circuits. The low tension bus is so sectionalized by means of disconnecting switches that the local feeders may be fed from either half of the station. A modification of this system utilizing the same number of low tension disconnects, utilizes the four sets of disconnects, shown for sectionalizing the low tension bus, for tying the combined generator and transformer bus to a low tension transfer bus, which low tension transfer bus supplies the current to the local feeders.

Special Bus.—Fig. 174 shows the general scheme of connections adopted for the original plant of the Rio Janeiro Tramways Light & Power Company controlling six generators, six banks of step-up

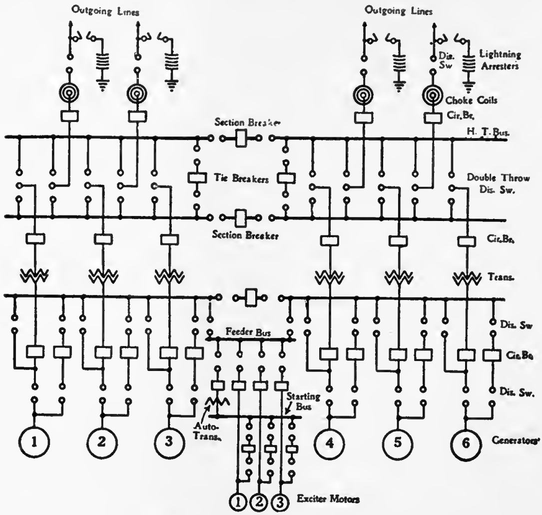


Fig. 174.—Diagram of connections for Rio de Janeiro.

transformers and four outgoing transmission lines. The plant is normally operated with each generator connected to the low tension side of its own transformer bank. Suitable breakers and disconnects are provided however, so that any generator may be connected to the low tension bus by a second oil breaker or the transformer bank may be connected to the low tension bus by disconnecting switches. The low tension bus is sectioned in the middle by means of breaker with disconnects, and the low tension feeder bus can be supplied from either half of the main low tension bus through proper disconnects. This feeder bus with

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auto transformers is arranged for furnishing current to the exciter motors.

On the high tension side each transformer bank is provided with a breaker and double-throw disconnects connecting to either of two high tension busses; these high tension busses are each split in the middle by means of section breakers and are tied together through tie breakers. The four outgoing lines are each provided with two sets of disconnects for connecting to either of the two sets of busses and an oil breaker. As the double-throw disconnects on the high tension side are of the selector type, any circuit can be connected to two busses at the same time, so that when it is desired to transfer a transformer or line circuit from one bus to the other this can readily be done and the work is facilitated by the use of the tie breakers so that no current will ever have to be opened on the disconnecting switches.

Flexibility.—Different engineers have their own ideas as to the amount of flexibility necessary or advisable in any particular plant, and the system adopted is frequently a compromise so as to secure a reasonable amount of flexibility with the minimum amount of switching equipment.

For the simpler plants using direct-control, panel mounted, devices, usually the single-throw system is adopted. For somewhat larger plants utilizing distant mechanical control oil circuit breakers, the single-bus or double-bus system can be used and normally sufficient space can be made available for the location of one or more sets of bus bars and suitable disconnecting switches.

For the largest plants using electrically operated breakers, practically unlimited choice is available as to the schemes of connections to be employed.

In the descriptions that follow of switchboard panels, some of these features of main connections are considered more fully, while the more complicated systems utilizing distant control devices are considered in connection with structures and station layout arrangement.

Largest Builders.—The main differences in the switchboards built by different manufacturers lie in the apparatus mounted on the panels and where the switchboard builder is also a manufacturer of instruments, switches, breakers, etc., he naturally prefers to use his own equipment. The two largest electrical manufacturers in the United States that build generators, transformers, synchronous converters and other power plant equipment are the General Electric Company and the Westinghouse Electric & Manufacturing Company, and the two of them together do the largest portion of the switchboard business in the United States, usually arranging to furnish the switching equipment for the control of their own machines, although this is not always the case.

The general features of switchboard design of the two companies in question have naturally been the result of their apparatus development and the competition for switchboard business has led to the desire for standardization to bring down manufacturing costs and to expedite production.

Other Builders.—There are of course a number of other switchboard builders competing for the switchboard business, particularly for the direct-current light and power work where there are many more different builders of generators than there are in A.C. work. The D.C. light and power switchboards for large office buildings are usually made according to specifications of an architect or engineer and usually do not conform to any particular standard of construction. For this class of switchboard work, the independent contractor and the small builder is often in a better position to carry out the architect's ideas than a large manufacturing company whose shop routine is designed especially for quantity production of standard equipment.

Treatment.—In treating the question of switchboards the general features will be taken up first, then the simpler D.C. boards, then the more complicated ones, these in turn being followed by the A.C. boards that are usually more involved and frequently affect the station design very materially. While the illustrations may seem to show the equipment of one builder more often than that of others, this does not imply any idea that it represents the actual relative proportion in which the various types are used in actual practice, but merely that the author found it simpler to utilize the illustrations that were easiest to obtain.

Differences.—In the usual illustration of a switchboard it takes an expert to distinguish what type of carbon breaker or knife switch is shown. Where oil circuit breakers are used the cover plates of different designs are more or less a distinguishing feature, and whether the meters are shown as rectangular or circular is often a clue to the builder of an A.C. switchboard, but comparatively few changes would be necessary to alter the appearance of the usual switchboard so that it would be difficult to tell what maker was responsible for it.

Standards.—As a result of the standardizing process the general practice of many switchboard makers is becoming more and more similar and one of the main ideas of the first part of this chapter will be to point out the gradual evolution of this standard practice and to give the reasons for various features. These reasons of course apply broadly to all switchboards both of the direct-control and the distant-control types. However, the former applying to moderate capacity plants followed "standard practice" more closely than the latter due to the many special features in large plants.

The earliest so-called panel boards were made of wooden panels with the various switches, instruments, etc., each on its own base and attached to the wooden panel with the wiring either on the front or the rear.

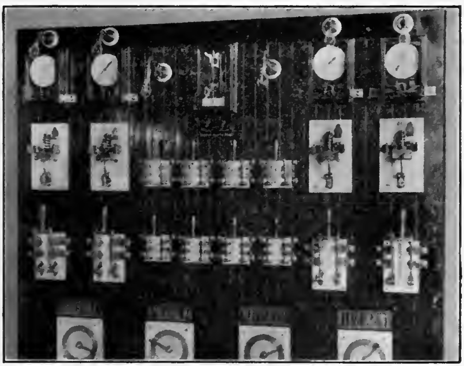


Fig. 175.—Wooden switchboard for Korea built 1887.

Wooden Board.—Fig. 175 shows a board of this type, built about 1887 for Korea and used for the control of four direct-current low voltage generators and eight feeder circuits. Each generator was provided with a pilot lamp, an ammeter, a single-pole carbon break circuit breaker, a 2-pole switch and a rheostat. Each of the eight feeder circuits had a

2-pole switch and a voltmeter was furnished with a voltmeter switch for connecting it to various circuits. The switchboard was made of tongued and grooved lumber with all of the wiring on the back and was strictly up to date at the time of its manufacture.

The next step in advance was the elimination of the wooden panel or framework. Each piece of apparatus was then mounted on a marble slab and was arranged for placing in an angle iron frame work and switchboards were made by combining the necessary ammeters, voltmeters, switches and rheostat slabs to make the panels for the different generators, feeders, etc.

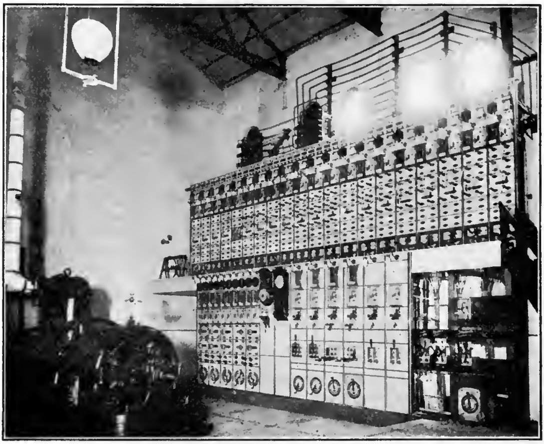


Fig. 176.—Panel Switchboard Brush Electric Co. of Baltimore 1894.

Old Panel Board.—Fig. 176 shows a large double-deck board of this design supplied to the Brush Electric Company of Baltimore about 1894 and used for the control of A.C. and D.C. generators and feeders. The five panels to the left on the lower floor were used for the control of five 1000 K.V.A. 2-phase A.C. generators operating independently, those being practically two single-phase machines with their armatures coupled together mechanically and displaced through an angle corresponding to 90 electrical degrees. Each panel had a pilot lamp, two ammeters, two voltmeters, two 2-pole double-throw switches, two sets of field plugs and two rheostat faceplates for the two separate field circuits used with the 2-phase machines. The next two panels with the bell and clock were station panels, the next four exciter panels, and the last two D.C. feeder panels. The balcony was devoted to A.C. feeder circuits each panel controlling a single-phase feeder which could be transferred by means of plugs and cables and a 2-pole, double-throw switch from any one of eight single-phase bus bars to any other bus.

This form of construction was entirely fireproof but various disadvantages ultimately led to its being superseded by the modern design of panel switchboards with the apparatus grouped on panels made of one or more comparatively large pieces of marble or slate.

Present Standards.—These lines of switchboards manufactured by various companies are the result of careful study of requirements. In general, the standard switchboards may be divided into two types with regard to their framework. The cheaper and smaller panels are mounted on a framework of gas pipe and usually comprise panels about 4 feet 0 inches high with a space below them. The larger and more expensive panels have a total height of about 7 feet 6 inches running down to the floor and are provided with an angle iron or pipe frame. For the small boards the frame is as shown in Fig. 177 made of vertical gas pipe one at each end of the board and one at the junction line of adjacent panels.

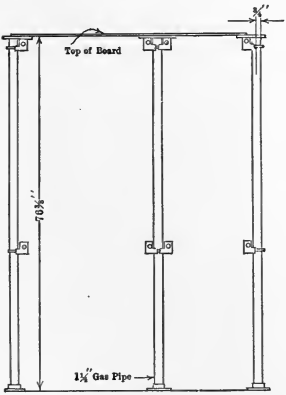


FIG. 177.—Pipe framework for small switchboards.

Special fittings are supplied for clamping to the pipe and a continuous flat strap ½ inch × 1⅜ inch in section running the length of the board is bolted to the fittings at the top of the pipe to stiffen the framework and to provide a suitable location for attaching wall braces, transformers, wiring, brackets, etc. The lower end of the vertical pipes are screwed into ornamental cast-iron bases which can be bolted to the floor.

These bases are circular and can be screwed on or off a short distance to allow for slight irregularities in the floor. Special fittings are designed for clamping to the upright pipes and the panels are bolted to these fittings. The entire design of this frame work has been made with the view of minimizing the amount of machine work and expediting the assembling of the frame. For small boards this type of frame has proved to be very satisfactory and a complete line of brackets to support bus bars, transformers, fuse blocks, regulators, etc., is available.

Pipe Frame.—While the gas pipe construction is considerably lighter than the angle iron construction it has been found amply secure for these smaller switchboards and in fact some manufactures use gas pipe construction for most of their larger switchboard installations. Where the number of panels does not exceed four or five the complete board can sometimes be shipped with the panels attached to the framework and most of the small wiring, etc., undisturbed but if the board is a large one the panels and frame are shipped separately

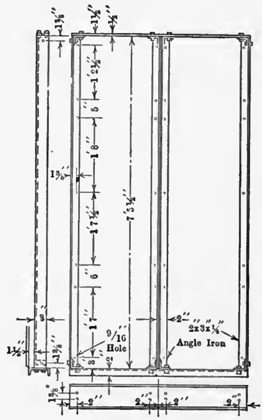


Fig. 178.—Angle framework for large switchboards.

Angle Frame.—For the larger and more expensive panels a framework of angle iron construction, Fig. 178, is used by certain builders. Each panel of a total height of 90 inches is provided with two 2 × 3 × ¼-inch angle irons or some similar section with the 2-inch side next the panel and these angle irons extend from the bottom of the panel to within ½ inch of the top. The vertical angles on adjacent panels are bolted together through the 3-inch web and are provided with corner angles for bolting at the bottom to a 6 × 2-inch channel iron forming the base of the frame and at the top to a ½ × 1⅜-inch flat iron. The channel iron and the top iron are made continuous and the entire length of the board provided same is not over 16 feet. Where the length exceeds this amount the frame is divided at the junction line of two panels. This arrangement makes a very stiff construction and the channel iron base makes up for any irregularities in the floor and distributes the weight better than a framework, where no channel iron base is furnished. The top provides a means of attaching wall braces, brackets, etc. Sometimes a flat soleplate or wooden sill is provided in place of the channel iron base or the vertical angles are connected directly to the floor.

Shipment.—Each panel is shipped bolted to the two angle irons that form its individual frame and this obviates any necessity of disconnecting the wiring between the various slabs making up the panel. The framework being shipped with the panels to a large extent reduces the breakage due to rough handling and facilitates the erection of the board at its destination. With a pipe framework the panels and uprights must be shipped separately, unless a temporary upright is furnished for each panel but one.

Material.—After trying various materials practically all switchboard builders have come to the use of either slate or marble although in a few instances soapstone, brick or steel has been used but these cases are so few that they can be left out of consideration.

Marble.—Marble used on switchboards is usually of the grade known as "Blue Vermont," although occasionally "White Italian" or "Pink Tennessee" is used. This is ordinarily beveled with a 45-degree bevel of either $\frac{3}{8}$ inch or $\frac{1}{2}$ inch measured in the plane of the front of the panel or its edge and not along the bevel. The marble is sometimes polished on the front face and bevels and occasionally the edges and back. Sometimes the marble or slate is given a polished black enamel finish but the present standard is a dull black marine finish applied to honed panels of marble or slate of any color or an oil finish applied to natural black slate.

Blue Vermont.—The name "Blue Vermont Marble" was originally applied to the marble of gray or bluish tint obtained from the quarries of the Proctor Blue Vermont Marble Company who supplied most of this grade of marble, but other quarries supply marble of practically the same kind. Polished blue Vermont marble in the opinion of many people presents a somewhat finer appearance than any other material available for switchboards but it has the drawback of showing oil stains and scratches and it is hard to secure a good match of shade and grainings for large switchboards. The difficulty of keeping an exact record of the shades and markings of the marble shipped to a certain customer who desires additions to his board militates somewhat against its use. The same remarks apply to English vein, white Italian or pink Tennessee marble.

Slate.—Ordinary slate owing to its irregular color and marking is seldom used in its natural state but is usually given an enamel or marine finish, while natural black slate is given an oil finish. Slate can be given a baked enamel finish of glossy black and with this finish oil has little effect and there is no difficulty in securing a good match. This finish is somewhat more expensive than the polished and has the same drawback of showing scratches, etc., which cannot well be removed or covered over without re-enameling. As this involves taking the panel from the board, removing all apparatus and baking the panel, this is seldom done. When a black enamel finish is given to marble trouble is apt to come from the marble crumbling during the baking process.

Marine Finish.—This finish as applied to panels of either slate or marble consists of a dead black paint, usually applied with an atomizer to a honed finished panel. This finish is cheap, very attractive, does not show oil stains, and if the panel is scratched a little, fresh paint will make it look as good as new. The dull black finish moreover, causes the instruments, switches, etc., to stand out in bold relief and has no tendency to reflect the light in the eyes of the attendant while polished or enameled panels have this tendency.

Oil Finish.—When natural black slate is used it is given an oil finish with vaseline or some similar material and it has practically the same advantages as the marine finish.

Slate vs. Marble.—Where switchboard panels are to be given a black finish the question of whether slate or marble should be used is largely a question of cost of insulation. Slate is considerably cheaper and somewhat stronger than marble and where the voltage of live metal parts mounted on the panels does not exceed 750 volts it answers just as well. This makes it suitable for all boards except those having ground detector receptacles, fuse blocks or similar apparatus mounted on the material of the panel and connected to a circuit of 1200 volts or more.

Small Panels.—The smaller and cheaper panels intended for use with gas pipe framework are made in single slabs and as a rule have a height of 48 inches and a width of 16 to 24 inches although some of the panels are smaller. In order to secure sufficient mechanical strength to stand the jar of oil circuit breaker opening, the panels are made of 1½-inch thick material for alternating-current service and panels with this thickness of 1½ inches have been usually adopted as standard.

Bevels.—A bevel is furnished on all of these panels to improve their appearance and also because it is almost impossible to secure marble or slate with a square edge that will stand handling. It has, in fact, been found advisable to use a small bevel or rounding of 1/16 inch or ⅛ inch on the back of the panel to prevent chipping off.

Early Panels.—When the building of small panel boards for A.C. and D.C. work was begun it was found by one large manufacturer that a height of 48 inches with a width of 32 inches for the A.C. panels and 22 inches for the D.C. panels was the minimum size that would permit the mounting of all of the then standard apparatus required with due regard to insulation distances and the lining up of apparatus on generator and feeder panels of various capacities and these particular sizes have been retained as standard.

Frame.—Where the standard frame is used with panels 48 inches high the bottom of the panel is 28⅜ inches from the floor and there is sufficient clearance to allow a sub-panel to be used. The height selected for the frame brings the meters in line with the operator's eyes and places the switches, rheostats, etc., in a convenient location. For the heavier lines of panels, 2-inch marble or slate has been adopted as standard for mechanical reasons. This thickness is required for the heavy switches, circuit breakers, etc., often furnished on these switchboards. These 2-inch panels are all provided with a ⅜-inch or ½-inch bevel on each front edge. With three division panels employing slate, the thickness is frequently reduced to 1½ inches.

Westinghouse Panel Sections.—The total height of standard switchboard panels of one design, viz., 90 inches from the channel iron as well as the division resulting in having a 25-inch lower slab on Westinghouse boards, is due to the fact that these particular dimensions were best adapted to the line of switches, circuit breakers, meters, etc., which were in use at the time when the standard railway switchboard panels shown in Fig. 179 were first brought out. The lower 25-inch slab was used for the rheostat faceplates having the contacts and contact mechanism on the rear and the handwheels on the front of the panel. In order to correspond with the old D.C. panels, the A.C. panels were brought out having a main slab 65 inches high.

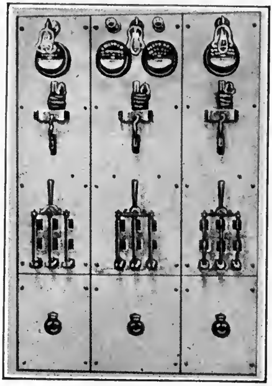


Fig. 179.—Old style Westinghouse two section switchboard.

G. E. Panel Sections.—While the Westinghouse Company was bringing out 65-inch × 25-inch panels, the General Electric Company working along their own lines and designing panels suitable for their apparatus, arrived at the same total height, but divided their panels into 2 slabs 62–28 inches high with a ⅜-inch bevel. This question of bevels and division of the panels is almost entirely a question of appearance.

Three Section Panels.—When the present standard laminated brush type carbon break circuit breaker was designed, it was found advisable to mount this breaker at the top of the panel in order to take advantage of the tendency of an arc to rise and to avoid placing apparatus above the arc. As all of the Westinghouse standard breakers up to 3000-amperes capacity required a space of something less than 20 inches, they soon decided to divide the main upper 65-inch panel into 2 slabs, one portion being 20 inches high to contain the circuit breaker, the other portion 45 inches high to contain the meters, switches, etc. By placing the circuit breaker on a separate slab, the calibration of the breaker was greatly facilitated. For this reason, the standard D.C. panels of the Westinghouse Electric & Manufacturing Company both for railway work and for light and power work were divided into 3 slabs, upper 20 inches high, the middle 45 inches, and the lower 25 inches, Fig. 180. With the growth in the capacity of synchronous converters, larger breakers than 3000 amperes became necessary, and these, while too long for 20-inch slabs, would go on 25-inch slabs so the latest Westinghouse panel division is 25 inches, 45 inches, 20 inches, and the G. E. division is 31 inches, 31 inches,

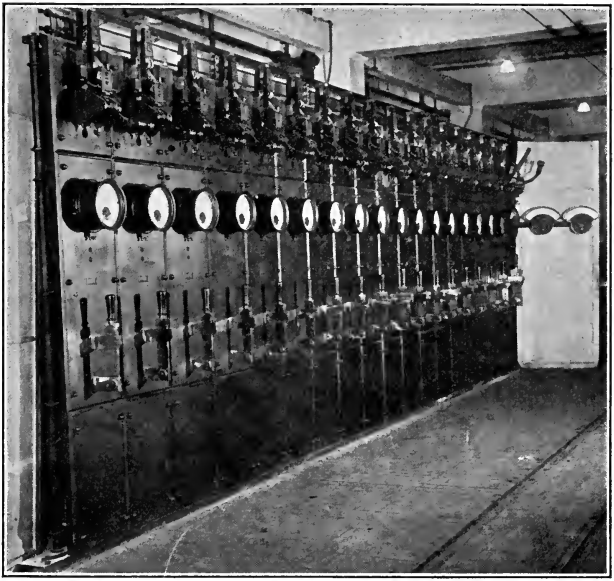


Fig. 180.—Westinghouse three section railway switchboard.

and 28 inches, Fig. 181. Nearly all switchboard builders are now following this practice of putting heavy circuit-breakers on separate slabs. Instruments are frequently placed below the circuit breakers on the 31-inch upper sections of G.E. panels.

Direct Control.—Direct-control switch gear is used with practically all direct-current plants and most of the smaller alternating ones and the main switching appliances are located directly on the switchboard which is usually of the panel type. Such boards are familiar sights in moderate size plants.

Many Builders.—Owing to the comparative simplicity of direct-control switchboards particularly for low voltage direct-current service the number of builders of this type of board is very large and the consequent competition has aided greatly in bringing about cheap and simple apparatus for this class of service. In order to meet close competition in the matter of cost and promptness of delivery nearly all switchboard builders have come to the practice of using so-called "standard panels" wherever possible and very complete "lines" of standard panels

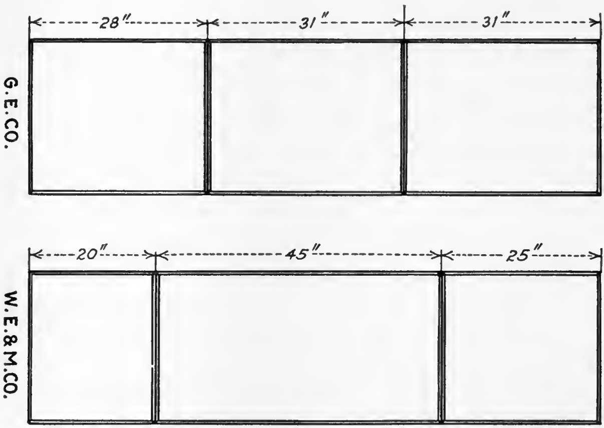


FIG. 181.—Three section panel.

have been designed to take care of all ordinary and some extra-ordinary features that are apt to be met with in plants of moderate capacity that can be satisfactorily handled by "direct-control switch gear."

Switchboards can be obtained to meet any possible requirement that may arise in the control and application of electrical power.

Standard Panels.—These have been designed using standard apparatus for various classes of services and these panels will be found to meet practically all ordinary requirements that may come up in switchboard installations.

Specials.—However, for special conditions that cannot be met by these standard panels, or where special material is desired, the extensive manufacturing facilities and long engineering experience of the companies insure that such propositions will be taken care of promptly and completely.

Requirements.—The selection of suitable switchboard apparatus for certain requirements is naturally governed by several conditions. In some cases first cost is the determining feature. In most cases continuity of service is of considerable importance. In many cases continuity of service must be provided regardless of cost. In all cases, the maximum degree of safety to life and property that can be obtained should be the goal. These, and other considerations, such as space available, voltage and capacity of plant, govern the proper selection of a switchboard equipment.

With regard to the kind of current controlled, switchboards are naturally divided into two broad classes: Direct-current switchboards and alternating-current switchboards.

D.C. Boards.—The direct-current switchboards cover a wide field and include in their range every application of direct current. In general, the direct-current panels may be divided into two classes—those of the larger capacities, and those of the smaller.

The larger boards are used for direct current railway systems and for lighting and power systems of large industrial plants, hotels, central stations, etc. The smaller generator and feeder panels are intended primarily for light and power systems of small industrial plants, small hotels and central stations of small capacity, etc., while the battery-charging panels are designed for controlling the charging of storage batteries used in lighting service and on electric vehicles.

A.C. Boards.—Alternating-current switchboards may be divided into the following three distinct classes, depending on the mounting and method of operation of the apparatus:

1. Direct-control boards, or those in which all apparatus is mounted on the panels or on their supporting framework.

2. Manual remote-control boards, or those with manually operated circuit breakers mounted apart from the board and operated by means of handles on the panels.

3. Electrical remote-control boards, or those with electrically operated circuit breakers mounted apart from the board and operated by means of control switches mounted on the panels.

Class of Board.—The particular class of board to be selected for any installation will depend on a number of considerations. For instance, the capacity of the station, the desired operating features, the allowable space, the permissible cost—all are factors in the selection of the proper type of board.

Limitations.—The capacity of a station determines the class of switching devices that can be used, and this in turn usually determines the class of switchboard to be installed. The desired operating features are a factor in the selection of either mechanically or electrically controlled apparatus. The allowable space may determine the type of equipment. The direct-control switchboard occupies less total space than any other, but sometimes involves more valuable space in the operating room than the remote-control, hence the disposition of the available space sometimes must be considered. With regard to cost, the direct-control board usually costs less than any other, although the saving in main cables, may sometimes be great enough with the remote-control boards to reduce the total cost of cables and switchboard to that of the direct-control, or to even less.

Direct Control.—The limitations in the use of the direct-control switchboards are chiefly electrical. Experience has demonstrated that there are certain limits of capacity above which oil circuit breakers should not be mounted directly on the panels. The reason for this limitation lies chiefly in the danger to attendants from high voltage apparatus when in close proximity to low voltage control and instrument wiring, rheostats, etc., which require inspection and occasional repairs, or from mechanical reasons resulting from the size and amount of copper busses and risers when the current involved exceeds certain amounts.

Remote Control.—Manual remote-control switchboards are limited in their application by the physical, rather than the electrical, characteristics. They are applicable where the simplicity of connections or accessibility desired cannot be obtained with panel mounted apparatus, where station capacity or voltage is so high as to make it desirable to mount oil circuit breakers apart from the panels, and where station arrangement permits the use of manually operated remote controlled oil circuit breakers.

Electrical Control.—The electrical control switchboard usually takes one of three general forms, namely: the panel board, the combination control desk and elevated instrument board, or the combination pedestal and instrument post board. All of these are detailed later.

Panels.—As in the application of the other types of boards there is no well defined field to which any of the three forms is confined. However, the panel board is frequently chosen for plants of moderate capacity, and, occasionally, for those of high capacity where the number of circuits are few and the length of the board is, kept therefore within a space which may be covered almost instantly by the operator. The panel board is usually chosen for substations, as it must generally harmonize with, and may be an addition to, the panel board controlling the direct-current and low tension alternating-current circuits.

Desks.—The combination control desk and elevated instrument board can be used for stations of any capacity and any number of circuits. The particular form chosen, however, must depend upon local conditions, but in general, for a small number of circuits, the linear desk is employed, while for a greater number of circuits, the semi-circular desk is most desirable as it permits a uniform view of all sections of the desk from one central position.

Pedestals.—When a station is equipped with very large units, pedestals for the control switches and receptacles, with posts for supporting the instruments, are sometimes used because of the complete individuality thus obtained for each unit.

On remote-control boards all busses and connections are shipped in bulk uncut. On panel mounted boards, if bus bars and connections are of strap, rod, or tubing, they are cut, bent and put in place; if they are of solid insulated wire they are shipped in reels, uncut, together with the wire for control and instrument busses and for primary leads of voltage transformers.

Panel Sequence.—The sequence of panels is important on account of the necessity for designing a switchboard to provide for future extensions, for the most economical distribution of bus bar copper, and to provide means for measuring the total load.

When a switchboard comprises generator, totalizing, and feeder panels only, the standard arrangement of panels when facing the front of the switchboard is to place the generator panels at the left, the feeder panels on the right, and the load or instrument panels between the two.

Bus Taper.—In fixing any arrangement of panels it is most practical and economical to locate the heaviest capacity panels next to the totalizing panels, the lightest capacity panels being located at the ends. The bus bar copper can then be tapered by the use of laminated bus bars. This construction reduces the amount of bus bar copper to a minimum and permits making extensions easily. A typical layout is shown in Fig. 182.

Location.—In many cases control apparatus and switching devices can be located to advantage near the machines controlled and save great expense in ducts and conductors, and avoid unnecessary complications. Such devices can be made electrically operated if the control is to be concentrated on one main switchboard.

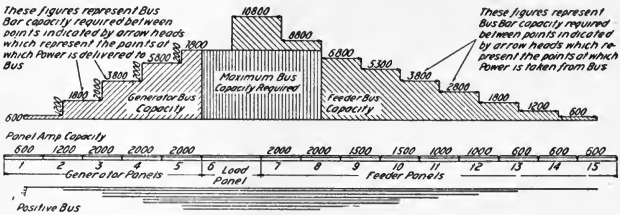


FIG. 182.—Typical bus bar tapering.

Copper.—The most economical distribution of conducting copper is frequently possible with remote controlled switching devices since the switching apparatus can be located to the best advantage without reference to the location or width of panels.

The amount of bus copper required for a switchboard equipment depends on the arrangement of panels and the distribution of circuits.

The amperes allowable per strap in the bus bar will vary according to the conditions of installation and service. The shape and dimensions of conductors, the relative position of conductors, and, in the case of alternating current, the frequency, all contribute to fix the effective capacity of a single strap in any given installation.

Carrying Capacity.—For alternating-current switchboards for capacities requiring but one strap, a 2-inch $\times$ ¼-inch strap will carry 550 amperes and a 3-inch $\times$ ¼-inch strap will carry 850 amperes at frequencies not greater than 60 cycles. For bus capacities above 2500 amperes, 60 cycle, or 4000 amperes, 25 cycle, careful designing is needed to secure the proper bus bar layout. In general, for bus capacities above the values given, the maximum temperature rise of the copper will exceed 28 degrees Centigrade, due to unequal distribution of current in the busses, since the inductive effect of adjacent busses causes increase in current density on one side of the respective bus bars and produces unequal heating of the straps forming the bus. Interlacing of phases or special arrangements of conductors can sometimes be adopted to secure a balance of the mutual inductive effects, better current distribution and more efficient use of the copper.

Exciter Bus.—Exciter bus bars ordinarily extend across the exciter panels and the alternating-current generator panels; and if used exclusively for the exciting current, their capacity need not exceed the total current required by the generator fields. The standard exciter bus bars for capacities up to 400 amperes is one 2-inch × 1/8-inch copper strap; up to 600 amperes, one 3-inch × 1/8-inch strap; up to 800 amperes, one 3-inch × 1/4-inch strap and up to 1200 amperes, two 3-inch × 1/8-inch straps.

Equalizer Bus.—The cross-section of the equalizer bus bar is in general made about one-half that of the positive or negative bus behind the generator panels.

Copper Sizes.—3-inch × 1/8-inch copper strap can be used to advantage for bus bar capacities up to 4000 amperes. 6-inch × 1/8-inch copper strap can be used to advantage for bus bar capacities above 4000 amperes up to 8000 amperes, 10-inch × 1/4-inch copper strap for bus bar capacities above 8000 amperes.

Ultimate Bus Capacity.—In designing a switchboard, an estimate should be made regarding the probable ultimate continuous bus capacity so that straps of proper dimensions and proper bus structures or supports can be utilized to take care of probable future additions.

In cases where the load is a fluctuating one, or the load factor is low, as in a synchronous converter substation of an interurban railroad the section of the bus can sometimes be safely reduced below that figured from the usual table.

Tubing—Carrying Capacity.—In high tension layouts, 22,000 volts and over, the connections and bus bars frequently consist of brass or copper tubing, iron pipe sizes. This tubing in standard lengths can be furnished on order when required.

The carrying capacities given below are based on a temperature rise of 28 degrees Centigrade. The sizes are iron pipe sizes.

For connections of moderate length, the capacity of 1 1/4-inch copper tubing may be increased to 800 amperes, other sizes in proportion.

Size of pipe, inches	Area in circular mils	Amperes		
		Copper bus	Brass bus*	Iron bus†
½	314,975	250	50	30
¾	426,816	350	70	42
1	601,381	500	100	60
1¼	884,176	725	145	87

*20 per cent. conductivity. †12 per cent. conductivity.

Panel Ratings.—The ampere rating of a switchboard panel corresponds to the capacity of the switches or circuit breakers mounted on the panel or controlled from it. The switches and circuit breakers are rated in accordance with the National Electrical Code and will carry their rated current continuously.

Switches and circuit breakers are given a maximum rating as they reach a final temperature quickly when carrying a steady current. Their capacity must, therefore, correspond to the one or two-hour overload capacity of the machine or circuit, if such a rating exists, in addition to its continuous capacity.

Temperature Rise.—The usual temperature rise guarantee for switchboard apparatus when carrying its rated current is 28 degrees Centigrade for knife switches, 30 degrees Centigrade for conducting parts of carbon and oil circuit breakers, and 50 degrees Centigrade for circuit-breaker coils and frames. Bus bars and connections are proportioned so as not to exceed 28 degrees Centigrade rise and instrument transformers are not allowed to exceed 50 degrees Centigrade. Shunts and resistances are exempt from temperature limitations. A room temperature of 40 degrees Centigrade is used as a basis. Where the room temperature exceeds this value, larger capacity apparatus should be chosen in order that the ultimate temperature will not exceed those fixed on this basis.

The maximum possible setting of overload circuit breakers should not be less than the momentary overload capacity of the machine or circuit.

Ammeter Scales.—Ammeters are commonly furnished with full scales corresponding to approximately 125 to 150 per cent. of the ampere rating of the panel. This allows for overload swings and yet gives good readability of scale at normal load. For railway service, D.C. ammeters are furnished with scales for the momentary overload capacity of the machine.

Switching Apparatus.—The switching apparatus on direct-current circuits consists of knife switches and carbon circuit breakers. Oil circuit breakers are not applied on D.C. circuits, as the breaking distances are proportioned for alternating current and are not great enough for direct current. In an A.C. circuit the current goes to zero with every alternation, thus assisting in breaking. The direct-current arc has a greater volume for the same current, and, besides requiring greater distances and oil volumes, the oil carbonizes much more rapidly, thus impairing its insulating value.

Oil Breakers.—Non-automatic oil circuit breakers can be used on standard high voltage direct-current arc lighting panels where the circuit is not over 10 amperes, and where the breakers are always opened by hand and then only infrequently. The rectifier arc regulators are commonly disconnected by opening the A.C. primary breaker first so that the D.C. secondary breaker need not be opened under load. Oil circuit breakers are used principally for the control of alternating current, and, hence, find their greatest application in connection with A.C. switchboards.

Ratings.—They are rated as to voltage, amperage, frequency, interrupting capacity and instantaneous current-carrying capacity. The voltage rating is the maximum voltage at which the breaker may be used and still meet standard A.I.E.E. rules on voltage tests. If the nominal voltage of the system equals the breaker voltage rating, which is a maximum, then in general the next higher voltage breaker should be used. The ampere rating is the maximum current for its guaranteed temperature rise.

Interrupting Capacity.—The ampere interrupting capacity of a circuit breaker is the highest current which it will open at any specified normal voltage, frequency, and duty. This capacity depends on the construction of the breaker. The duty on which ampere interrupting values are based assumes that the breaker will interrupt a circuit twice in succession at an interval of 2 minutes and then be able to carry its normal current until such time as it is convenient to inspect it and make necessary adjustments.

In order to protect the circuits controlled by a switchboard from damage due to sudden overloads some device may be connected in the circuit that will automatically break it when an overload is applied. The devices used are fuses or automatic carbon or oil circuit breakers, depending on the nature of the circuit or apparatus to be protected.

Meter Equipment.—The selection of the proper meter equipment for a switchboard depends on the class of board employed, the number of lines controlled, etc. In general, a careful selection of suitable meters is of more importance on the larger boards, especially the electrically operated, than on the smaller ones, for the reason that many more economies can be introduced in the operation of a large station by skilled operators with a suitable meter equipment than would be possible in a smaller plant. On all boards, a multiplicity of meters should be avoided and only those necessary to give the information desired should be used.

D.C. Meters.—On D.C. switchboards, the meter equipment is usually quite simple, consisting generally of one voltmeter arranged for switching to each generator circuit, one ammeter for each generator circuit, and an ammeter only for the feeder circuits except in cases where feeders may be energized from an outside source, when provision should be made for reading the feeder voltage. On the smaller boards, the ammeter may be dispensed with on the feeder panels.

A.C. Meters.—When the load is not always balanced, alternating-current generators should be equipped with an ammeter in each phase, or with one ammeter and a polyphase ammeter switch if simultaneous readings are not desired. In case the load is always balanced, a single ammeter is all that is necessary.

If generators operate in parallel they should have an indicating wattmeter and a field ammeter in addition to the main ammeter. If cost is a serious consideration, either one may be omitted but not both.

Indicating Wattmeter.—This will indicate the total instantaneous energy load on the machine regardless of power factor or distribution of load. Two machines of the same size operating in parallel may have the same curent output, but, through improper field adjustment one machine may be supplying all the load or even driving the other machine as a motor, without the ammeters indicating any abnormal condition.

Field Ammeter.—This serves to indicate the proper adjustment of field current so that windings will not be overloaded. It is also convenient as a means of determining the cause of any abnormal conditions in the generator.

Power factor meters or reactive factor meters may be used in addition to, or in place of, indicating wattmeters, but a comparison of the wattmeter reading with the corresponding readings of the voltmeter and ammeter will give a general indication of machine power factor.

Bracket Instruments.—Voltage readings of machines in parallel are usually taken by means of a "machine" voltmeter (which is usually mounted on a swinging bracket) connected to voltmeter switches on the individual panels. Most operators desire a second voltmeter mounted on the same bracket with the machine voltmeter and connected permanently to the bus bars. This arrangement permits a simultaneous comparison of the bus bar and machine voltages when synchronizing.

A synchronoscope, mounted on a swinging bracket, for indicating synchronism when connecting an incoming machine to the bus bars, usually forms part of the equipment. This instrument is often supplemented with two 110-volt indicating lamps, connected to be dark at synchronism, to be used as a check and as a reserve in case the synchronoscope is removed temporarily. A machine or bus frequency meter is frequently advantageous.

Feeders.—Alternating-current feeder circuits are usually supplied with ammeters as a general indication of the feeder load. Other meters such as frequency meters, power factor meters, indicating wattmeters, watt-hour meters, etc., are supplied according to the requirements of each particular case.

Ground Detectors.—Ungrounded systems should be equipped with some form of ground detector for indicating grounded circuits. For systems up to and including 600 volts, the ground detector usually consists of incandescent lamps capable of withstanding full bus bar voltage, connected in series from each bus bar to ground, so as to form a continuously indicating detector.

For 2200 volts and above, static ground detectors may be used. These are operated from condensers or resistors connected to the bus bars in order to obviate danger from high voltage in the instrument. The detectors must be rigidly mounted so that the position of the leads cannot be changed.

Rheostats.—Field rheostats are usually operated by means of a handwheel on the front of the panel, from which a shaft extends through the panel to the rheostat, or to a sprocket for remote control.

Rheostats that are sufficiently small, such as exciter field rheostats and voltage limiting rheostats, may be supported on a tetrapod mounting on the rear of the board immediately back of the handwheel and operated directly through the shaft.

In practically all cases, however, generator field rheostats should be mounted apart from the switchboard and operated through a sprocket-and-chain transmission except where electrical operation is desired. The faceplates are usually mounted directly on the resistance frames and wired completely before shipment. When individual exciters are used with the generators, the exciter field rheostat may be mounted in combination with the generator field rheostat. With this mounting, the handwheels and shafts for the two rheostats are mounted concentrically, the main rheostat being controlled through the outer shaft and the exciter rheostat through the inner shaft.

Safety Code.—On account of the general adoption of the National Safety Code either as a legal requirement or as a standard of reference in courts of law in many states, with the probability that it may become the basis on which all safeguards against accident or damage to persons are provided, it is recommended that the Code be taken into account in the application, installation and operation of the switchboard apparatus. In general, the purchaser should provide a competent operator and such guards, shields, insulating mats, isolation, warnings, and other requirements to make the installation comply with the Code as may be recommended, unless he does otherwise at his own risk.

CHAPTER XII

SMALL D.C. & A.C. SWITCHBOARDS

For small industrial plants, hotels, garages, etc., switchboards with panels 48 inches high or less mounted on light pipe framework are built by various manufacturers. While the practice of the different builders naturally varies, the descriptions that follow may be taken as fairly representative of this class.

BATTERY CHARGING PANELS

Sectional Type.—The sectional type of battery-charging panels on single frame shown in Fig. 183 are designed primarily

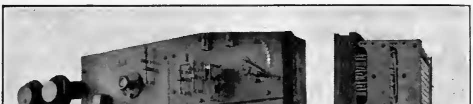


Fig. 183.—Sectional type of battery charging board.

for use in public and private garages where electric vehicles will be charged. The charging rheostats specified are designed for charging batteries recommended by the Society of Automotive

Engineers, namely, 40 to 44 cells for lead batteries and 60 to 62 cells for Edison batteries.

Each panel consists of three or more sections, together with charging rheostats. This sectional construction provides a large variety of combinations, thus making an installation very flexible, as the number of charging circuits may be increased at any time after the switchboard has been installed, by the addition of suitable sections and rheostats.

Rheostat.—Each battery-charging rheostat consists of a resistor of cast-iron grids supported on the rear of each panel section between steel end frames with contact buttons and moving arm on the front of the panel section. Bolts through the panel hold the end frames of each charging rheostat to the panels so that the rheostat forms an integral part of the section equipment. By disconnecting the wires connecting the grids to the contact button terminals, the resistor can be easily removed from the panel.

Assembly.—The sections of each panel are assembled one above another and securely bolted to a vertical angle iron frame of suitable height. The simplest panel consists of one or more charging sections and a power control section mounted above the charging sections. Swinging brackets at the side of the panel will mount the power section ammeter, if used, and the battery voltmeter and ammeter. It is not advisable to use panels exceeding 90 inches in height, because some of the switching apparatus would be inconveniently high for the operator, and, therefore, when more sections are required than can be mounted on a frame 90 inches high, they may be arranged in two or more panels of uniform height. Where the number of necessary sections is not sufficient to make all panels the same height, blank sections may be provided for some of the panels.

Generator Section.—Every switchboard or panel which controls one or more direct-current generators must be equipped with an individual power control section for each generator. If generators are compound wound and generator control sections with circuit-breaker protection are used then one side of the generator switch will be connected to the equalizer bars, the other side to the negative bus, and the circuit-breaker will be connected in the positive lead. If generator control section provides fuse protection only, then an equalizer switch must be provided.

Locations.—A rule, incorporated in the National Electric Code, specifies that charging panels located in garages where gasoline is handled must have all spark producing devices mounted 4 feet or more above the floor. If such devices are mounted less than 4 feet above the floor, the charging panel must be surrounded by a vapor-proof enclosure, unless the panel is located in a room or enclosure provided for this purpose.

Platform.—Switchboards or panels controlling several charging circuits will regularly have the switching apparatus mounted less than 4 feet above the floor and the purchaser is expected to install the panels as provided for by the Code. In most cases, the simplest method is to mount the board on a concrete platform 4 feet high.

Protection.—The arrangement of the panel sections, and combination of them, is such as to provide a maximum of protection to the operator. Power control sections employing carbon circuit breakers will be located at the top of the panel. The contactors on the charging sections are provided with blowout coil and shields. The operator is thus protected against possible injury due to moving parts or to the arcing of automatic devices.

The various sections are made up of slabs 1 inch thick, ¼-inch bevel. These sections are of two heights, 14 inches and 28 inches, depending upon the apparatus mounted on the section.

Ampere-hour Meter Sections.—These are equipped with ampere-hour meters of the auto type, with a zero contact reset device and variable resistor element. The meter is designed so that it will run "slow," when the charging current of a battery passes through it, the speed being adjustable to approximately compensate for the charging efficiency of any battery. When a given number of ampere hours for which the meter has been set have been supplied to the battery, the pointer will again be at the zero position and will close the zero contact. This will cause the contactor in the circuit to open, thus terminating the charge. Therefore, to charge a battery, it is only necessary to set the meter pointer at the ampere hours, as previously discharged from the battery, and when this number of ampere hours (automatically corrected for charging efficiency by the resistor element of the meter) have been returned to the battery it will be automatically disconnected.

When ampere-hour meter sections are used, for the purpose of automatically terminating the charge of a battery, it is necessary to use charging sections, employing a contactor.

Rheostats.—Each power control section to be used for the control of a direct-current generator is drilled for a field rheostat mounting of the switchboard type.

Each switchboard that controls a source of power such as a direct-current generator must be equipped with a ground detector outfit. For such panels, two 110-volt incandescent lamps are furnished and are mounted with the generator ammeter on the swinging bracket. Each of the lamps is connected between one side of the line and ground, thus forming a continuous indicator. Under normal conditions each lamp will glow red due to the fact that it is operating on about one-half normal voltage. If the positive line becomes grounded, the lamp connected to that line will grow dim or cease to glow at all, while the other lamp will increase in brilliancy. If the negative side is grounded, the order of brilliancy is reversed. When power is received from incoming direct-current lines the lamps are not required.

Overload Protection.—Plain overload protection is regularly furnished for all sections. For this purpose there is furnished for each charging circuit a National Electrical Code fuse holder and enclosed fuse for each side of the circuit.

To protect the battery ammeter against overload, a fuse is provided and is connected between the battery ammeter bus bar and the main negative bus bar. This fuse is regularly mounted on a bracket on the rear of the panel.

When it is desired to use two or more battery ammeters independently, each ammeter must be protected by its own fuse.

If each charging circuit is to be protected against reversal of current, it is necessary to select charging sections and power control sections for this service.

Power Control.—Power control sections with circuit breaker protection are regularly furnished with a low voltage release mechanism attached to each circuit breaker to protect the source of power against reversal of current. When this circuit breaker opens, due to reversal of current, the auxiliary contacts with which the circuit breaker is supplied will open all charging circuits which are provided with magnetically operated switches.

In case power control sections equipped with fuse switch protection and with low voltage relay switch are used, the reversal of current will cause the low voltage relay switch to open and thereby open all the charging circuits, if charging sections with contactors are used.

Low Voltage.—The low voltage coil of the carbon circuit breaker and of the low voltage relay switch will be suitable for 115 volts D.C. In case the generators are driven by A.C. induction motors, it is possible to obtain A.C. low voltage coils, so that on failure of the A.C. power the low voltage relay switch and carbon circuit breaker will be tripped.

Reversal.—However, when several generators operate in parallel and obtain their power from separate sources it will be necessary to use reverse current relays, in order to insure absolute protection against the occurrences of reverse current.

From the battery standpoint, it is very desirable to have battery circuits protected against reverse current. If only the generator or main circuit is protected against reverse current, the batteries remain connected in parallel to the bus bars (after the circuit breaker opens). Therefore, the batteries having the highest terminal voltage will discharge into the other batteries connected to the system.

Reverse Protection.—The use of the low voltage release mechanism, as part of the circuit breaker equipment, or the use of the low voltage relay switch, is adaptable for protection against the reversal of current from a storage battery, because at ordinary temperatures (from 60 degrees to 90 degrees Fahrenheit) the voltage of a good battery discharging at the normal rate is always lower than the minimum voltage required to start the charging of that battery at the normal starting rate. Furthermore, the charging resistance connected in series with the battery further reduces the voltage across the coil of the circuit breaker or the low voltage relay switch (upon reversal of battery current), thus insuring the tripping of the breakers or the low voltage relay switch.

Meter Switch.—Each charging section is equipped with a special 2-pole knife switch which may be moved to a position (without opening the circuit) so that the battery ammeter and voltmeter are connected to the charging circuit, thereby indicating the charging rate in amperes and the voltage of the battery at once.

Rheostats.—The battery-charging rheostats usually provide 12 steps. The standard rheostats are usually designed for a particular number of cells. However, each rheostat may be used for charging a battery composed of a slightly larger number of cells, requiring the same charging rate, but it must be observed that in this case the number of resistance steps available for adjustment will be reduced. If a battery is to be boosted at a rate higher than that scheduled, a special rheostat will be required.

Lead Batteries.—For lead batteries, the voltage applied across the battery terminals will be increased as the charge progresses

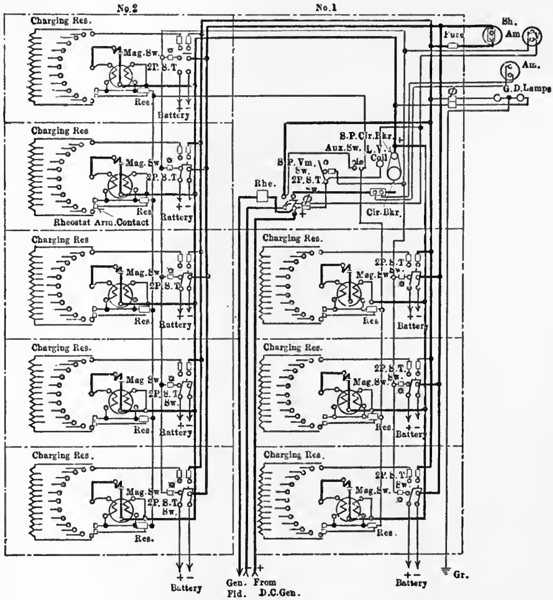


FIG. 184.—Diagram of connections with magnetically operated switches.

and the charging current will be maintained approximately constant, that is, at the given starting rate until near the end of the charging period; then the current will be reduced to a given finishing rate, and will be maintained approximately constant throughout the remainder of the charging period.

Edison Battery.—For nickel-iron (Edison) batteries the voltage applied across battery terminals will be increased as the charge progresses and the charging current will be maintained approximately constant at the required rate.

Connections.—Fig. 184, shows the diagram of connections with magnetically operated switches.

LIGHTING AND CHARGING PANELS

Light and Battery.—Where a switchboard is desired for controlling the charging of batteries used in lighting service and on electric vehicles, but only one battery is to be controlled instead of using the sectional type a somewhat simpler construction is employed as shown in Fig. 185.

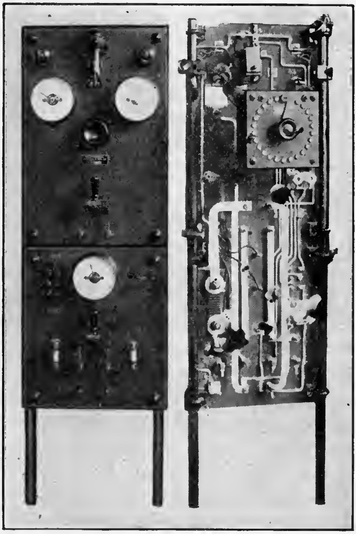


Fig. 185.—Light & battery panels.

One class of panels is intended for use in residences and small isolated plants that have a battery to supply current for lighting and a generator for charging the battery. Only single panels are made and the capacity of the generator panels is limited to 75 amperes, while the battery panels are limited to a normal capacity of 60 amperes. On single section panels the limit is 100 amperes for both generator and battery circuits. The circuit breakers are equipped with reverse current attachments in addition to the plain overload trip which will open the circuit in case the charging current is interrupted, and thus prevent the discharge of the battery.

When battery-charging apparatus is required with a generator panel, it will be mounted as a lower section of the panel, except when a single section generator and battery-charging panel is specified.

Conditions.—Three conditions are provided for in charging batteries with these panels:

First, 50-volt generator charging 30-volt battery connected directly to the mains.

Second, 125-volt generator charging 30-volt battery. The battery is charged through a suitable resistance.

Third, 125-volt generator charging 125-volt battery. The battery, in this case, is charged with two sections in parallel, each section being connected through a suitable charging resistance. A fixed resistance is used for this work, the variation in voltage being taken care of by varying the field of the generator.

Constant Potential Charging.—This method of charging is the constant potential charging method; that is, the battery is thrown directly on the circuit and allowed to become charged. When the battery and charging circuit voltages differ sufficiently to produce a charging current of such a value that it may be injurious to the battery, a charging resistance is necessary. The value of the resistance depends on the number of cells in the battery; type of cells (or voltage at beginning of charge and at the end of charge); charging current desired; and the line or generator voltage. A variable resistance, that is provided with faceplate and rotating arm, mounted apart from the board, can be used to obtain the constant current method of charging. However, if there are but one generator and one battery circuit, the constant current can be obtained by adjusting the generator field rheostat.

Generator Battery.—Where a panel is chosen to control a lighting circuit in addition to generator and battery circuit, the generator voltage must be maintained for the lighting circuit, and consequently a charging resistance is necessary, either of the fixed or variable type. Electric vehicle charging panels are made for private service, where one battery is to be charged and the charging current is taken from an outside source. They can, however, be used when the current is furnished by a motor-generator set or engine driven generator, by adding the field rheostat for the generator to the panel and in the case of the motor-generator sets by mounting one of the lower sections on the same frame.

The reverse-current mechanism furnished with the carbon circuit breaker depends for its action on the sum of the voltage and current coil fields. The voltage coil field is the stronger field on small reversal and strong enough at zero current setting of the reverse-current devices to trip the breaker.

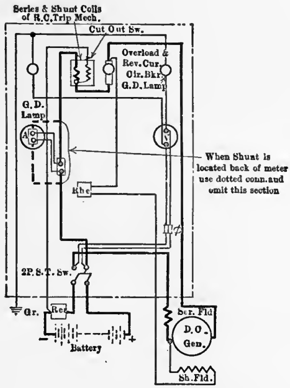


FIG. 186.—Connections of generator and battery panel.

Panels.—The generator panels are a modification of the small generator panels described later in that the circuit breaker is equipped with reverse-current trip. The current coil in the relay is designed for the same carrying capacity as the circuit breaker and the relay is calibrated to operate with a battery which has the same capacity as the generator, or greater. In case the battery is so small that it requires only a portion of the generator capacity to completely charge it, a special relay or extra switches may be required. Lower sections are provided which correspond in type to the lower sections regularly used with the generator panels.

The lower sections are for use with 30-volt batteries, and with 125-volt batteries. These when combined with the generator panel form the complete panel for controlling generator and battery for private service.

Fig. 186 shows the connections of a single section battery panel charging the battery with all cells in series.

COMBINATION GENERATOR AND FEEDER PANELS

Where the panel is not used with a battery the reverse-current attachment is left off the breaker and the panels are designed to provide a complete switchboard in a single panel of one or two sections to control one generator with not more than four feeders.

They are intended for small isolated plants operating direct-current systems of 250 volts or less.

Limits.—The capacity of a panel is limited to 400 amperes for the generator, and 200 amperes for each of two feeder circuits, or for 60 amperes for each of four feeder circuits. Each panel forms a complete switchboard and is not designed to have panels added to it.

Panel Size.—The panel consists essentially of either one or two sections of slate 1 inch thick, 16 inches wide, with ¼-inch bevel on front edges; the upper section being 24 or 36 inches high, and the lower section, 12, 18 or 24 inches high. The upper section contains the apparatus for the control of the generator and the lower section contains that for the control of the various feeder circuits.

Frame.—The frame is light and simple, being made from ¾-inch gas pipe uprights which are screwed into floor flanges. The total height of the frame is 65 inches. It is fitted with wall brace ends for ¾-inch gas pipe. Pipe and foot for bracing the frame to the floor or wall can be supplied at a small additional price.

Switches.—Single-throw knife switches are used for generator and feeder circuits. When it is desired to provide for a separate source of power, the generator panel can be furnished with a double-throw switch. This switch will be mounted horizontally instead of vertically.

Protection.—Automatic protection is provided for the generator circuit by a single-pole carbon circuit breaker, or by enclosed fuses mounted on the front of the panel. Feeder circuits are protected by enclosed fuses mounted on the front of the panel.

SMALL PLANT SWITCHBOARDS

The next larger size of D.C. panels using slabs 48 inches high on pipe framework are particularly adapted to the control of from one to three generators in small industrial plants and central stations operating direct-current 2 wire systems of 250 volts or less.

Limits.—The capacity of a single generator panel is limited to 600 amperes, and that of a complete switchboard composed of these panels to 1500 amperes, with the number of panels limited to six. For greater capacities, a switchboard composed of 90-inch high panels is recommended.

Panels.—Each panel consists of a single slate slab 48 inches high by 12, 16, 20 or 24 inches wide, 1½ inches thick, with ⅜-inch bevels on front edges, bolted at the four corners to the switchboard frame. This frame is made of 1¼-inch pipe uprights, resting on floor flanges and supporting the necessary panel and top iron brackets, to which the panel is bolted. The total height of the panel is 76⅜ inches.

Automatic protection is provided for the generator circuits by single-pole carbon circuit breakers, or enclosed fuse blocks mounted on the front of the panel; for feeder circuits by single-pole carbon circuit breakers, enclosed fuse blocks on slate bases mounted on brackets on rear of panel.

MINING SWITCHBOARDS

Switchboards of this type are suitable for substation service in mining installations controlling motor-generator sets or synchronous converters typical panel arrangements being in line with Fig. 187 with connections as shown on Fig. 188.

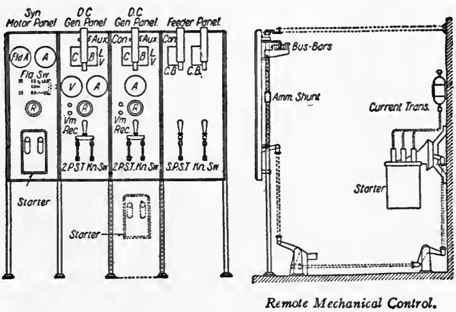


FIG. 187.—Arrangement of M.G. panels for mine service.

Scope.—These mining panels are particularly adapted for the control of small direct-current generators and A.C.–D.C. motor-generator sets, operating 2-wire, grounded negative, direct-current systems of 600 volts or less; and for the control of small 275-volt converters for mine service, operating 2-wire, grounded negative, direct-current systems.

Engine Generators.—Panels for the control of 275-volt, direct current, engine driven generators are in general similar to generator panels shown, except the connections on the rear are made for a grounded negative with one pole of the 2-pole circuit breaker being connected between the armature and the series field and equalizer connections, and the other between positive and bus. As the negative side of the circuit is grounded, no

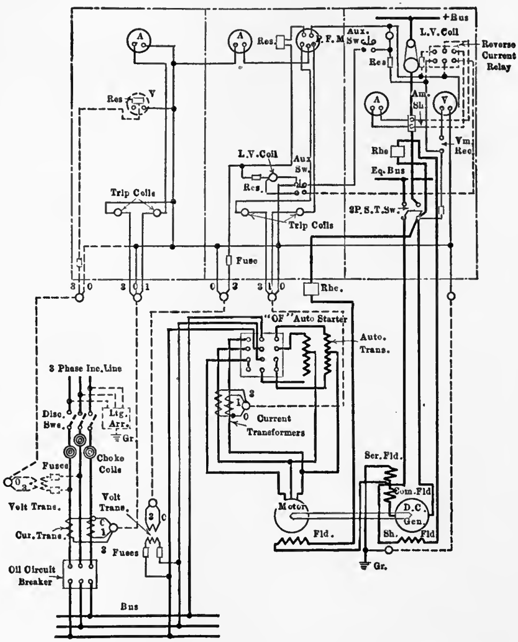


Fig. 188.—Diagram of connections for M.G. sets for mine service.

ground detector outfit is supplied. The voltmeter switch is two point, the negative side of the voltmeter being connected to ground.

Panels for the control of 600-volt, engine driven generators are similar to the 275-volt panels described above, except that 600-volt apparatus is supplied.

Motor Generators.—Panels for the control of direct-current generators which are part of motor-generator sets, with overload protection in the motor circuit, will have the connections modified in that the single-pole carbon circuit breaker will be inserted in the positive side of the circuit. The carbon breaker will also be equipped with a low voltage release for tripping it when the motor breaker opens.

Feeders.—Panels for the control of feeders are similar to light and power feeder panels, except that a single-pole knife switch is furnished in place of each 2-pole switch, and the switches are for 600 volts for the 600-volt panels.

Motors.—Panels for the control of induction motors are furnished in the form of sub-panels to be mounted directly below the direct-current generator panel, on the pipe frame legs.

Panels for the control of self-starting synchronous motors are furnished as separate switchboard panels to stand adjacent to the direct-current generator panel.

Starters.—The A.C. motor starter is a double-throw oil circuit breaker, non-automatic for starting, and automatic with overload inverse time limit and low voltage release for running. The handles are mechanically interlocked so that the starting side of the breaker must be closed first and that the running side can only be closed within a fixed time interval after starting side had been opened.

The starting position magnetizes the auto transformers and connects the motor to the starting voltage, the tap leads of the transformer being permanently connected to the motor leads. In passing to the running position the auto transformers are disconnected from the line and full-line voltage is applied to the motor.

The starter for 3-phase service is 4-pole double throw with special moving contact arrangement.

Starting Combinations.—As an alternative, a combination of remote mechanically operated automatic 3-pole and non-automatic 4-pole type breakers can be had. The 3-pole breaker constitutes the running breaker. It is overload automatic, with inverse time limit and low voltage release mechanisms. The 4-pole breaker is the starting breaker; it magnetizes the auto transformers and connects the motor to the starting voltage from separate handles mechanically interlocked so that one breaker only can be closed at one time. A two handle cover plate will be supplied and current transformers for use with the automatic breaker.

This combination is made for remote mechanical operation only and is applicable only for starting with two single-phase auto transformers.

The switching equipment for motors of capacities exceeding the ratings of the double-throw breaker are made up of either two or three single-throw breakers as follows:

Motors started by means of two single-phase auto transformers have a standard 3-pole running breaker and a special 4-pole starting breaker; motors started by means of a 3-phase auto transformer have a standard 3-pole running breaker and two special 3-pole starting breakers operating in tandem.

Time Element.—The inverse time element feature is provided in connection with the overload trip on the circuit breaker or auto starter, so that the motor circuit will not be opened on momentary overloads, such as obtain when the switches are moved from the starting to the running position. The time in which the overload trip will operate is inversely proportional to the amount of overload, tripping being instantaneous in case of a short circuit.

The overload tripping range is usually from 80 to 160 per cent. of the current rating of the current transformers included with the panel equipment.

Low Voltage.—All circuit-breaker equipments have a low voltage trip which opens the running breaker when the voltage has dropped to approximately one-half its normal value. This feature is included to guard against an excessive current due to the return of power to a motor which may be out of phase or at rest. For voltages up to and including 550, the low voltage coil with series resistance is connected directly to the line. For higher voltages, a voltage transformer with primary fuse blocks and fuses is included.

Auxiliary Switch.—The handle of the running circuit breaker is equipped with an auxiliary switch which serves to operate the low voltage trip circuit of the direct-current generator breaker of the motor-generator set, when the alternating-current breaker opens.

Reversal.—If the direct-current generator of a motor-generator set operates in parallel with an independent source of direct-current power, the set will run inverted upon the interruption of the alternating-current power and hold up the alternating-current voltage. The independent source of direct-current powermay be a motor-generator set (or a synchronous converter) supplied from a separate alternating-current source, a generator driven by a prime mover, or a battery. In order to prevent motoring from the direct-current bus bars, and to disconnect the set, a reverse-current relay should be included with the direct-current generator panel equipment and so connected as to trip the alternating-current breaker upon current reversal. With the electrical interlock mentioned in the preceding paragraph the direct-current breaker is tripped on the opening of the alternating-current breaker and the set is thus completely disconnected in case of alternating-current power interruption.

Rupturing Capacity.—The short-circuit amperes which the breaker may be called upon to interrupt must be considered in every case before applying the standard equipments. If the total capacity of generating and synchronous apparatus connected close to the motor is sufficient to deliver, under short circuit, a current in excess of the rupturing capacity of the running breaker included in the standard equipment, special consideration is necessary. It may be possible in this case to modify the standard equipment by replacing the dashpot inverse time limit attachment by direct trip attachment, and relay equipment giving a definite minimum time delay, and thus avoid the necessity of a heavier duty breaker. Where the interrupting capacity required is more than twice the rating of the breaker in the standard equipment, it is necessary either to replace the running breaker by one of suitable interrupting capacity or supply a breaker of suitable interrupting capacity in series, which is set to open ahead of the running breaker of the standard equipment in case of a short circuit. The breaker at the power house may often serve this purpose where the motor is supplied from a transmission line. In the latter case the breaker of the standard equipment must be given a definite minimum time delay as mentioned above. It may be necessary also to use heavier duty starting breakers on a heavy capacity system.

Auto Reclosing Breakers.—These circuit breakers can be applied where it is desired to insure that circuits will not unnecessarily remain open when overload conditions have been removed. Power is automatically put back on the circuit, as soon as conditions permit, and the expensive delays due to failure of power is reduced to a minimum.

Automatic reclosing circuit breakers can be furnished in place of the plain, automatic, carbon breakers. The automatic reclosing circuit breaker is essentially a solenoid operated breaker, the main contacts being held closed by the action of a solenoid. When an overload or short circuit occurs on the load side of the line the solenoid circuit is caused to open. This remains open for a definite time, resulting in an immediate opening of the carbon breaker (owing to a dashpot element), and then automatically closes only when the overload or short circuit has disappeared. Auxiliary devices are usually necessary.

When two or more generators operate in parallel and each generator circuit is provided with an automatic reclosing breaker, a special master relay is required so that all generator breakers will be opened or closed simultaneously.

When the feeder circuits are not independent, but tie in with feeder circuits from other stations, a feeder relay is required with each tie-in feeder circuit to control the reclosing of the automatic reclosing breaker with reference to the load conditions, whether the line is energized from the remote source of power or not, at the particular time the breaker opens. This applies also to the automatic reclosing breaker of the generator circuit if there is only one connected to the bus from which several tie-in feeder circuits are fed, or to the master relay if there are several generators operating in parallel on a tied-in system.

When there is the possibility of a reversal, the generator breakers should also be equipped with a special reverse current relay which slips over the studs of the breaker.

Synchronous Motor Panels.—These usually have no field switches. A self-starting synchronous motor is usually started with the field circuit closed through the armature of its individual exciter if connected to the motor shaft; or if no exciter is provided and the motor is excited from the direct-current generator which it drives, the motor field is closed through the generator armature. The motor field is thus short-circuited at stand-still and is gradually excited as the motor comes up to speed.

A 2-pole double-throw field switch must be supplied when the motor field is excited from a separate source of power, or from an exciter not connected to the motor shaft. The left-hand switch studs are connected together by a copper strap. The field switch is in the left-hand position until the motor has come up to synchronous speed. It is thrown to the right-hand or normal position before the motor is connected to full line voltage.

The rheostat is in series with the field in the starting position as well as in the normal position of the field switch.

Motor-generator Sets.—When these are used for 275-volt direct-current service they have the motor field excited across the direct-current generator terminals. Motor-generator sets for 550 volt direct-current service may have a separate 125-volt exciter connected to the same shaft, or the motor field may be excited from an exciter independent of the motor-generator set.

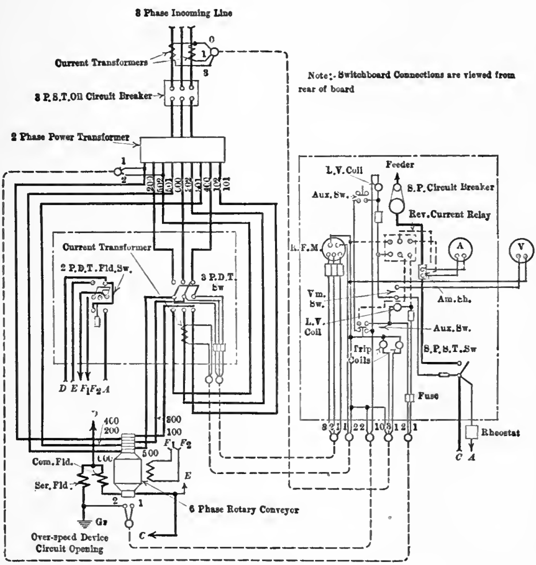


FIG. 189.—Diagram of connections for synchronous converters for mine service.

For synchronous converter service in mines, combination A.C.-D.C. panels can be supplied containing carbon breaker, ammeter, voltmeter and knife switch for the D.C. circuit, reactive factor meter and oil breaker for A.C. with a separate panel for starting with connections as per Fig. 189.

Combination Panels.—For isolated plant service combination panels can be provided to control one D.C. generator and any number of D.C. feeders up to four. These panels are intended for use in isolated plants operating a single D.C. generator of 250 volts or less and not over 600-amperes capacity.

Each panel consists of a single slate slab, 48 inches high by 20 inches or 24 inches wide, by 1½ inches thick, with ⅜-inch bevels on front edges, bolted at the four corners to the frame. The total height is 76⅜ inches.

Automatic protection is provided for the generator circuit by a single-pole carbon circuit breaker, or by enclosed fuses mounted on the front of the panel; for the feeder circuits, by enclosed fuses mounted on the front of the panel.

The main connections on the back of the panels are of bare copper strap and are cut, bent, and assembled before shipment.

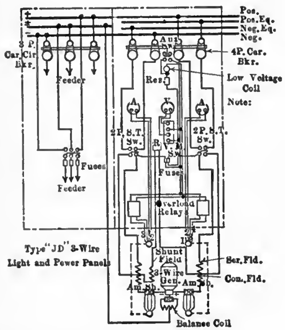


FIG. 190.—Connections of three-wire generators with four-pole breaker.

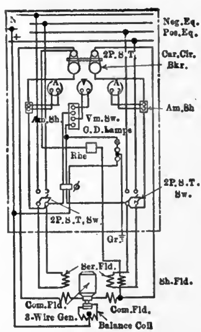


FIG. 191.—Connections of three-wire generators with two-pole breaker.

Three-Wire Panels.—These 48-inch high panels are also suitable for use with 3-wire D.C. generators connected to utilize 4-pole circuit-breaker protection as shown in Fig. 190, or 2-pole circuit-breaker protection as shown in Fig. 191.

These 3-wire switchboards are designed for the control of from one to three generators in lighting and power plants of moderate capacity operating direct-current 3-wire systems.

The capacity of a single generator panel is limited to 600 amperes, and that of a complete switchboard composed of three panels to 1500 amperes. For greater capacities a switchboard composed of 90-inch high panels is recommended.

Each panel consists of a single slate slab 48 inches high, $1\frac{1}{2}$ inches thick, with $\frac{3}{8}$-inch bevels on front edges, bolted at the four corners to the frame. The frame is made of $1\frac{1}{4}$-inch pipe uprights, resting in tapped floor flanges with the necessary panel and top iron brackets. The total height is $76\frac{3}{8}$ inches.

Meters.—Polarized ammeters and voltmeters are regularly furnished with these panels. With the ammeters there are supplied ammeter shunts for mounting on the generator frame, and shunt leads 40 feet long.

Switches.—Knife switches, either single or double throw, are used on generator and feeder panels. Switches are not provided for disconnecting the balance coils from the collector rings on the generator, as these circuits can be opened by lifting the collector brushes. If switches are desired in these circuits, double-pole single-throw knife switches can be provided and mounted on the panel, or on a sub-panel. The omission of these switches from the balance coil circuits effects a saving, as it eliminates the necessity of running cables from the collector brushes and balance coils to the switchboard.

Protection.—Automatic protection for the generator circuit is provided by a 4-pole carbon circuit breaker automatically tripped through relays actuated by the full armature current, or by a 2-pole double coil overload carbon breaker.

Automatic protection for feeder circuits is provided by 2-pole circuit breakers, three single-pole circuit breakers actuated by a common trip, or enclosed fuses.

Where generators are operating in parallel, positive and negative equalizer bus bars are necessary in addition to the main bus bars. These extend behind the generator panels but are not continued back of the feeder panels.

Code Rule.—With 3-wire direct-current generators, the National Electrical Code requires that the "safety device consist of either a double-pole double coil overload circuit breaker, or a 4-pole circuit breaker connected in the main and equalizer leads, and tripped by means of two overload devices, one in each armature lead." In short, the National Electrical Code requires that the safety device be actuated by the full armature current.

Comparison.—A Comparison between the two methods shows the following:

Two-pole breaker protection requires:

2-pole carbon breaker.

Six leads between generator and switchboard. (See diagram of connections.)

Cable duct and installation of same for six main generator leads.

Ammeter shunts mounted on switchboard.

Two sets of short ammeter shunt leads.

Four-pole breaker protection requires:

4-pole carbon breaker with low voltage release device for tripping by relays.

Two overload relays.

Four leads between generator and switchboard. (See diagram of connections.)

Cable duct and installation of same for four main generator leads.

Ammeter shunts mounted on generator frame.

Four sets of ammeter shunt leads of a length at least sufficient to reach from ammeter shunt on generator frame to meters and relay on board, through main lead or separate ducts.

Costs.—From the above comparison, it can be seen that the cost of the switchboard panel equipment is greater with the 4-pole breaker protection than with the 2-pole breaker protection. However, the added cable and cable duct cost, including also the added expense of installation, may be found to make the cost of the total equipment greater with the latter method of protection than with the former. This becomes true as the distance between the generator and the switchboard increases, and as the size of the cables and ducts increases.

The following table gives the distance between generator and switchboard beyond which it will be found in general that the total equipment cost of 2-pole breaker protection will be greater than total equipment cost of 4-pole breaker protection.

200 kw.	250-volt generator	18 feet
150 kw.	250-volt generator	22 feet
100 kw.	250-volt generator	28 feet
75 kw.	250-volt generator	33 feet
60 kw.	250-volt generator	38 feet
50 kw.	250-volt generator	40 feet
25 kw.	250-volt generator	50 feet

WELDING PANELS

For welding service 48-inch panels can be utilized to advantage. Welding by means of the electric arc is accomplished by drawing an arc between a metal or carbon electrode of an electric circuit, and the metals to be welded. The electrode is usually the negative terminal of the circuit, whereas the metal to be welded is the positive terminal. Direct current is commonly used for arc welding, as it requires less current than alternating for the same welding effect and also gives the better results.

Processes.—Arc welding is divided into two commercial processes: Carbon, or Graphite, Electrode Process, in which the arc is drawn between metal to be welded and a carbon, or graphite, electrode; and the Metal Electrode Process, in which the arc is drawn between metal to be welded and a metal electrode.

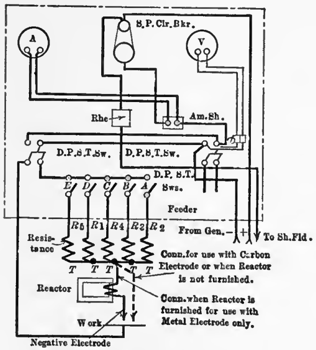


FIG. 192.—Diagram of connections for welding panels.

The current for arc welding may be obtained from any convenient direct-current source, although it is commonly taken from a motor-generator set. Several welding circuits can be connected to one generator circuit, the number depending on the capacity of the generating equipment and on the number of operators working at any one time.

Where only one welding circuit is connected to the generator, both the generator circuit and the welding circuit may be controlled from a single switchboard panel, which is known as a combination control panel connected as per Fig. 192, or an individual generator panel may be used to control the generator and a separate outlet panel to control the welding circuit. Where several welding circuits are connected to one generator circuit, the generator may be controlled either from a separate generator panel or from a combination control panel; in the latter case one of the welding circuits is connected to the combination panel and the remainder to outlet panels, while in the former case an outlet panel must be provided for each welding circuit.

Capacities.—The combination generator and welding panels range in capacities from 150 amperes to 1000 amperes for the generator equipment and up to 750 amperes for the welding equipment. On the 1000-ampere combination panel the control for the welding circuit is of 750-amperes capacity; on all other combination panels the control for the welding circuit is of the same capacity as the generator circuit. The separate generator panels are for capacities ranging from 150 to 1000 amperes; the outlet panels are for capacities of 200, 350 and 600 amperes.

Each panel consists of a single section, 48 inches high by 16, 20 or 24 inches wide, and 1½ inches thick, with ⅜-inch bevels on front edges, except the metal electrode outlet panel, which is 36 inches high. The panels are mounted on 1¼-inch pipe frames, complete with floor brace, the total height of which is 76⅜ inches.

Single-pole carbon circuit breakers provide automatic overload protection for both the generator and welding circuits.

LOW VOLTAGE A.C. SWITCHBOARDS

For moderate capacity low voltage A.C. circuit switchboards are particularly designed for the control of from one to three generators in small industrial plants and central stations operating alternating-current systems below 500 volts. Fig. 193 shows a typical 440-volt switch board.

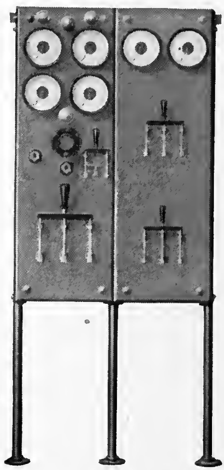


Fig. 193.—Arrangement of small 440-volt Westinghouse switchboard.

Limits.—The capacity of a single generator panel is limited to 600 amperes, and that of a complete switchboard composed of these panels, to 1500 amperes, with the number of panels limited to five. For greater capacities, a switchboard composed of 90-inch high panels is recommended.

Panels.—Each panel consists of a single slate slab 48 inches high by 16 or 20 inches wide, 1½ inches thick, with ⅜-inch bevels on front edges mounted on a 1¼-inch pipe frame. The total height of the panel is 76⅜ inches.

Protection.—No overload protection is provided for the main or field circuits of alternating-current generators. The panels for feeder circuits include enclosed fuses mounted on the rear of the panel.

Meters.—On generator panels, one ammeter is furnished for each phase. On feeder panels, one ammeter is furnished for each 2, or 3-phase circuit.

The generator panels are designed to have the exciter rheostat supported on a tetrapod mounted on the rear of the panel, with the generator rheostat separately mounted and operated by a sprocket-and-chain transmission.

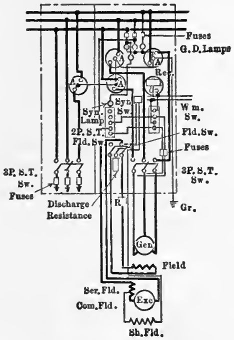


FIG. 194.—Diagram of connections 440 volt A.C. switchboard.

Synchronizing.—These panels are designed for synchronizing between the incoming machines and the bus bars. A six-point synchronizing switch and an incandescent lamp are furnished with each generator panel and one synchronizing key is supplied with each switchboard, with connections as per Fig. 194. A synchronoscope with the necessary voltage transformers can be supplied, if desired.

Each generator panel is designed to have the generator field connected through a 2-pole switch with field discharge contacts to a single exciter. If parallel operation of exciters is desired, exciter panels are needed.

HIGH VOLTAGE A.C. SWITCHBOARDS

Similar panels are available for 1200–2400 volts and up to 200-amperes capacity. These switchboards are particularly adapted to the control of single or parallel operated alternators in small industrial plants and central stations, see Fig. 195.

Limits.—The capacity of a single generator or feeder panel is limited to 200 amperes and that of a complete switchboard to 400 amperes. For greater capacities, a switchboard with 90-inch panels is recommended.

Panels.—Each panel consists of a single slab, 48 inches high by 1½ inches thick, with ⅜-inch bevels on front edges, bolted at the four corners to a 1¼-inch pipe frame. The total height of the panels is 76⅜ inches.

Protection.—Standard panels provide no automatic protection for the main or field circuits of alternating-current generators.

When a single generator panel controlling one feeder is installed, automatic protection for the feeder side of the non-automatic oil circuit breaker may be obtained by providing a subsection with fuses, to be mounted immediately below the generator panel on the frame. An automatic oil circuit breaker can be substituted for the non-automatic circuit breaker and fuse section. The advantages of the automatic circuit breaker are that it is quickly and easily closed after opening the circuit,

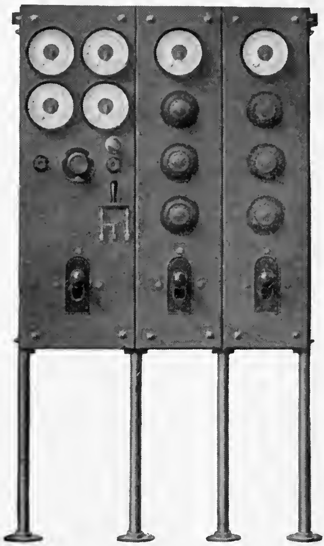


Fig. 195.—Arrangement of small 2400-volt Westinghouse switchboard.

cannot be held in a closed position while an overload condition exists on the line, and eliminates the trouble and expense of replacing the fuses.

The generator panels are designed to have the exciter rheostat supported on a bracket mounted on the rear of the panel, with the generator rheostat separately mounted and operated by a sprocket-and-chain transmission.

Each generator panel is designed to have the generator field connected through a 2-pole field switch with field discharge contact, to a single exciter. If parallel operation of exciters is desired, exciter panels should be ordered.

Ground Detector.—A voltage transformer having a lamp across its secondary and arranged for connecting to each bus wire is supplied for indicating grounds.

Synchronizing.—A synchronizing receptacle and an incandescent lamp for synchronizing between machines are furnished with each generator panel. The same transformer used in connection with the voltmeter is used for synchronizing. If synchronizing between bus and machine is desired, one voltage transformer with fuses for connecting to bus is needed. A synchronoscope can be supplied if desired.

Feeder panels are supplied with overload automatic oil circuit breakers or non-automatic oil circuit breakers with rear connected fuses. These fuses are removable from the front of the panel, but have no live parts exposed.

CHAPTER XIII

LARGE HAND AND ELECTRICALLY OPERATED PANEL SWITCHBOARDS FOR D.C. GENERATORS AND SYNCHRONOUS CONVERTERS

Standards.—For the control of D.C. generators, the D.C. end of synchronous converters and D.C. feeders for 250 volts, 2-wire and 3-wire light and power service and 600-volt railway service, panels with a total height of 90 inches have been standardized by various switchboard builders. The original Westinghouse panel divisions for this class of switchboard were 65 and 25 inches,

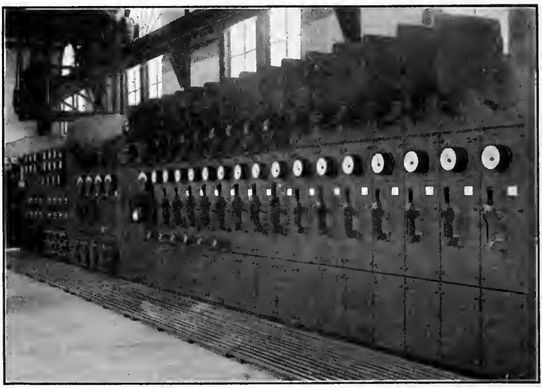


FIG. 196.—Westinghouse railway switchboard.

and corresponding G. E. divisions being 62 and 28 inches. The present three section panels of these companies are 25 inches, 45 inches and 20 inches, and 31 inches, 31 inches and 28 inches respectively. Other switchboard builders have used these or other panel divisions with the same total height.

Westinghouse Railway Switchboard.—Fig. 196 shows a typical Westinghouse switchboard installed in a large synchronous converter substation. Like most switchboards for railway service, there is only one D.C. polarity, the positive, brought to the board, the negative and equalizer busses running between the machines and not being located on the switchboard panel.

The ten panels near the right-hand end of the switchboard are feeder panels having single-pole carbon break circuit breakers connected to the main 600-volt bus at their upper stud, the lower stud being connected to the top stud of the knife switch, and the ammeter shunt being located in the strap connections between the breaker and switch. The next six feeder panels are provided with double-throw knife switches instead of single-throw, the lower throw of these knife switches connecting to a transfer bus, this transfer bus in turn being connected to the main bus through a circuit breaker and switch. With this arrangement any of these six feeder circuits can be operated either through its own circuit breaker or through the circuit breaker on the transfer panel.

Beyond the feeder panels are D.C. load panels, panels for the D.C. end of the converter, panels for the transformers feeding the converter, and panels for the incoming A.C. line circuit.

On this particular switchboard where the panel sections are 20 inches, 45 inches and 25 inches, the upper sections of the D.C. panels are reserved for the carbon circuit breakers, the middle for the instruments and switches and the bottom sections of the feeder panels are left blank. On the D.C. converter panels the bottom sections contain watthour meters, while on the A.C. panels these contain relays.

G. E. Power Switchboard.—Fig. 197 shows a typical General Electric double polarity 2-wire power station switchboard controlling four generators and eight feeder circuits. With the arrangement shown, the positive, negative and equalizer leads of each generator are brought to the switchboard. The two generator panels at right-hand end of switchboard each have a three-pole switch, while the two at the left-hand end have each three single-pole switches. The carbon breaker is in the positive circuit of each generator. Each of the feeder circuits is provided with a carbon breaker in the positive circuit and a knife switch in the negative circuit.

With these three-section panels divided into sections 31 inches, 31 inches and 28 inches, the upper 31 inch sections are reserved for circuit breaker and meter, while the middle section contains the knife switches on the feeder circuits, and on the generator

Fig. 197.—General Electric Co. three section switchboard.

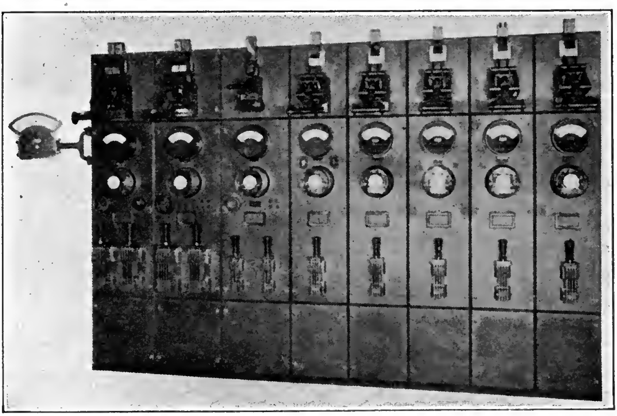


Fig. 198.—Pittsburgh Electric Co. switchboard, front view.

circuits the field rheostat and voltmeter receptacle in addition to the knife switches. Two D.C. voltmeters, located on a swinging bracket, are placed at the end of the board.

Pittsburgh Electrical Power Board.—Fig. 198 shows a somewhat similar D.C. switchboard built by the Pittsburgh Electric and Machine Works, utilizing Cutter (I.T.E.) circuit breakers, Weston indicating meters, Sangamo watthour meters and knife switches

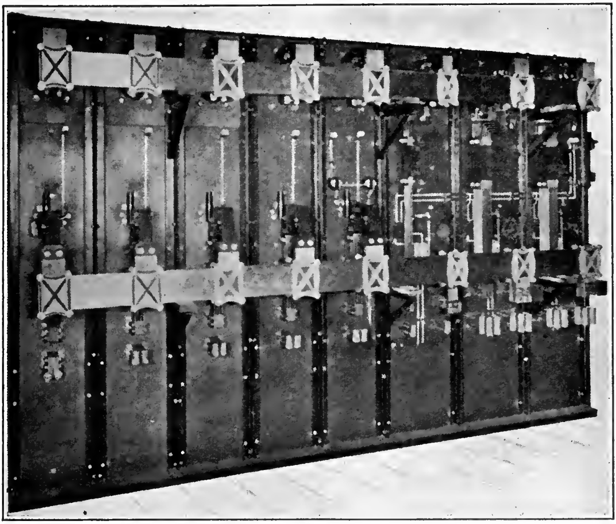


Fig. 199.

of their own design. This is a double polarity switchboard controlling two 750-K.W. Synchronous converters and a smaller unit as well as five outgoing feeder circuits.

Fig. 199 shows the rear view of this same switchboard illustrating the angle frame iron construction and the simplicity of the bus bar arrangement due to the use of laminated stud circuit breakers and switches.

This switchboard has its panels in three sections, 20 inches, 50 inches and 20 inches high, the top slab being reserved for the carbon circuit breaker, the middle slab for the instruments and switches, and the lower slab being left blank.

Cutter 3-wire Breakers.—For use with 3-wire D.C. generators that are provided with series fields in the positive and negative circuits, a special arrangement of 4-pole carbon breaker is furnished by the Cutter Company as shown in Fig. 200.

With this arrangement the main positive and main negative circuits are run from the armature of the generator to the circuit-breaker stud passing through the overload coil with a reversal feature in one circuit, thence to the lower outside main stud, the

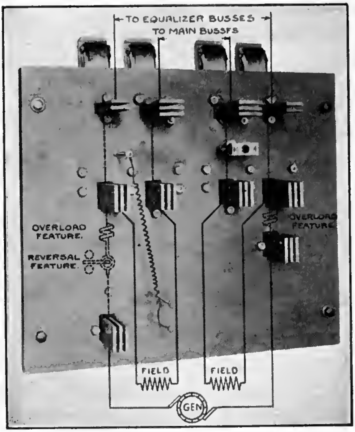


Fig. 200.—Cutter circuit breaker for three-wire generator.

leads being then brought back to the generator in order to pass through the series fields in the positive and in the negative circuits. The two outer poles of the circuit breaker connect to the positive equalizer and the negative equalizer busses, while the two middle poles connect to the positive main bus and the negative bus. When the breaker operates through overload or reversal, all four poles trip out at once, thus opening the positive, positive equalizer, negative and negative equalizer circuits.

Electric Operation.—Where it is feasible to furnish an electrically operated breaker located right at the machine, a 2-pole breaker is frequently furnished for connecting in the armature leads. Such a breaker completely opens up the generator armature circuit, but will normally leave the series coils connected across between the positive and positive equalizer bus, the negative and the negative equalizer bus.

Neutral Lead.—With most 3-wire generators the neutral lead is obtained from the neutral point of an auto transformer or balance coil connected across two collector rings. This neutral is normally grounded and frequently no switches whatever are furnished for use in the neutral circuit.

SPECIAL ISOLATED PLANT SWITCHBOARDS

In isolated plants, factories, or large office buildings the design of the switchboard is frequently based on specifications issued by the consulting engineer or architect, and these very seldom follow out the designs that have been standardized by the larger manufacturing companies.

Such isolated plant switchboards as a rule control a comparatively large number of feeder circuits, and it becomes necessary to control a number of feeders from each panel, such an arrangement usually resulting in a special design of switchboard for each individual case.

Walker Switchboard.—Fig. 201 shows a fine example of a switchboard of this type built by the Walker Electric Company, and installed in the plant of the Curtis Publishing Company, of Philadelphia.

This switchboard utilizes Cutter circuit breakers, Weston vertical edgewise group mounted feeder ammeters, Weston flush mounted illuminated dial instruments and controls the output of eight 2-wire, 250-volt generators and two 3-wire balancers, the total generating capacity being approximately 3000 K.W.

An eight section control desk located in front of the switchboard controls the generators and is provided with flush mounted illuminated dial Weston ammeters and the control switches for the electrically operated generator breakers, the motor operated field rheostat, etc. The control desk as well as the panel board is of gray marble.

The panel board is made up of one station panel, two balancer panels, five lighting and six power panels. Each of these lighting and power panels controls six circuits, so that there are a total of 66–2-wire feeders controlled from this board, each equipped with a 2-pole circuit breaker and an ammeter. Knife switches

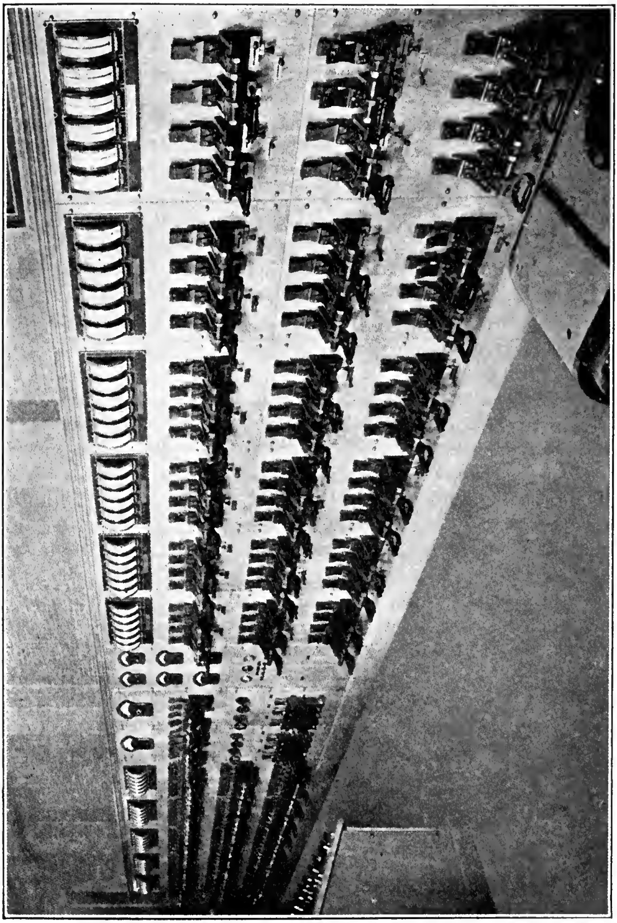


Fig. 201.

are entirely absent from the switchboard with the exception of those required for the three wire balancers.

As the circuit breakers in the feeder circuits embody the non-closable on overload feature, no switches are needed in series with them.

Short Circuit Conditions.—For light and power service at 250 volts in plants of moderate capacity, particularly when fed from D.C. generators in place of synchronous converters, the short-circuit conditions on the carbon breakers are not so severe, and the resulting arc is not as intense as encountered in railway sub-stations of large capacity operated from synchronous converters.

Carbon break circuit breakers can, therefore, be utilized to advantage, placed one above the other on switchboard panels for this class of service, whereas for railway work it becomes almost essential to locate them at the top of a panel so that the resulting arc cannot damage the panel and will have ample space in which to extinguish itself.

Circuit-Breaker Protection.—Single bus railway panels provide automatic overload protection in one side of the circuit only; namely, in the positive side, opposite the series field. This protection is sufficient for synchronous converters with overload protection on the alternating-current side and for motor driven generators with overload protection in the motor circuit.

Engine Generators.—There is a possibility in using this single protection with engine driven railway generators having the negative lead grounded, that the circuit breaker in the positive side does not protect the generator against possible damage due to a ground either in the machine or on the positive side between the machine and circuit breaker. An additional circuit breaker mounted on a pedestal and installed in the negative armature lead, is required by the National Board of Fire Underwriters. This breaker, when provided, has an auxiliary switch, so that upon the opening of the breaker, the switch will act in connection with the low voltage release mechanism of the positive breaker and cause it to open. It is recommended that the negative breaker be set higher than the positive breaker on the switchboard and thus permit the latter breaker to take care of the ordinary overloads.

Converters & M.G. Sets.—Direct-current panels for synchronous converters and motor generators, 2-wire or 3-wire D.C. service, regularly include a reverse-current relay operated from the ammeter shunt, in addition to the low voltage release mechanism supplied with the direct-current circuit breaker. An A.C. low voltage coil is supplied on converter panels and a D.C. low voltage coil on generator panels. For 3-wire service one reverse-current relay or attachment will be found sufficient in all cases except when it is possible that battery charging may be done, at times, from one side of the circuit only. In this case, two reverse-current relays are necessary for absolute protection.

Two Wire.—Two-wire light and power panels provide automatic overload protection in only one side of the circuit, namely, in the positive side opposite the series field. This is approved as sufficient protection by the National Board of Fire Underwriters.

Three Wire.—Three-wire light and power panels are required by the National Safety Code to operate with the neutral grounded. They provide complete automatic overload protection on both sides of the machine. Except with three wire booster converters, which are shunt machines, a 2-pole carbon circuit breaker with equalizer contacts is regularly furnished by the Westinghouse Company for machines of guaranteed capacity of 2000 amperes and below for one or more hours. For machines of larger capacities a 4-pole breaker is regularly furnished consisting of a positive and negative pole of capacity suitable for the machine, and two equalizer poles of approximately half the capacity of the main poles. The Westinghouse breaker is tripped through overload relays, operated from the ammeter shunts located on the generators and connected in the circuit between the armature and the equalizer leads.

Three wire booster converters have no compound windings and their panels are furnished with an overload automatic 2-pole carbon breaker. No overload relays are necesary, and the ammeter shunts are mounted on the panel.

Panels controlling the direct-current side of a synchronous converter or motor generator have the circuit breaker equipped with a low voltage release mechanism having, an A.C. coil for converters and a D.C. coil for generators, to open the breaker by the operation of the speed limit device when furnished and to provide means of tripping the direct-current breaker upon the opening of the alternating-current breaker.

Meters.—Round pattern polarized ammeters and voltmeters are regularly furnished with these panels. Illuminated dial instruments may be substituted. The full scale of ammeters corresponds approximately to the momentary overload guarantee of the machine.

Reactive factor meters are supplied by the Westinghouse Company with synchronous converter D.C. panels. They give an emphatic indication of the idle component of the volt amperes. These instruments are single phase and will indicate the reactive factor of one phase of the 6-phase synchronous converter. As the phases are balanced, this is sufficient for all operating conditions.

The General Electric Company furnish a reactive volt ampere indicator reading reactive K.V.A. for the same service.

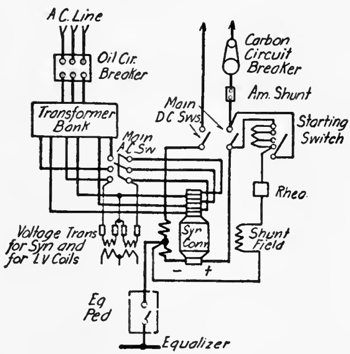


FIG. 202.—Diagram of D.C. starting of synchronous converters.

D.C. Starting.—When D.C. starting of motor driven generators and synchronous converters is desired, the standard panels must be modified. The purpose of these additions is shown in the diagram, Fig. 202. The single-throw auxiliary switch is open when the main switch is open. This switch opens the tripping circuit of the reverse-current relay during starting, making it impossible for the reverse-current relay to trip the alternating-current breaker until synchronizing has been done and the direct-current voltage adjusted, so that the machine when switched in will operate in the normal direction. The auxiliary switch is also in series with the auxiliary switch of the alternating-current automatic breaker and opens the interlock connection with the direct-current breaker, so that the latter can be closed for starting while the alternating-current breaker is in the open position.

The equalizer switch is double throw to cut out the series field in starting.

A.C. Panels.—The panels used for the control of the A.C. end of synchronous converters and their transformers are usually made to line up with the D.C. panels.

Protection.—Automatic protection on the alternating-current side of the synchronous converter is provided on the high tension side of the step down transformer by an instantaneous overload oil circuit breaker, tripped from current transformers. The breaker is also equipped with low voltage release and auxiliary switch. A low voltage trip instantaneous overload carbon circuit breaker is provided for the direct-current side. In the majority of railway applications involving capacities of 1000 K.W. and below it is advisable to eliminate the overload feature on the D.C. breaker. The low voltage coil of the direct-current breaker is connected to the low tension transformer leads in parallel with the low voltage coil of the A.C. breaker. The speed-limit switch furnished with and mounted on the converter, opens upon overspeed and causes both A.C. and D.C. breakers to trip simultaneously.

The low voltage coil on the D.C. breaker is also actuated by an auxiliary switch that is always provided on the oil circuit breaker so that when this breaker opens, the direct-current breaker also opens, thus providing against motoring from direct-current power and eliminating the liability of reversal in polarity on compound wound machines. Reverse-current relays are also provided on the D.C. panel, arranged to open the alternating-current breaker upon reversal of direct-current power, which in turn opens the direct-current breaker. The reverse-current relay may be omitted only if the converter is not interconnected with an independent source of direct-current power, so that there can be no reversal upon the interruption of the alternating-current supply.

Transformers.— Transformer primary circuit-breaker equipments constitute part of the complete switchboard equipment for the control of alternating-current self-starting synchronous converters.

These equipments usually comprise one 3-pole, single-throw instantaneous overload, automatic oil circuit breaker, of one of the following types:

1. Hand operated, remote mechanically operated, instantaneous overload, automatic oil circuit breaker, complete with two 5-ampere trip coils, low voltage release mechanism coil and hand-reset device and auxiliary contact to interlock with D.C. breaker.

2. Electrically operated 125-volt D.C. control, oil circuit breaker, with two 5-ampere trip coils at breaker, instantaneous overload.

In case inverse time element is desired with the breaker equipment, two overload relays may be added to the electrically operated circuit breaker. With the remote manually operated oil circuit breakers only, inverse time element attachments can be furnished with the circuit breaker.

Starting Panels.—These provide for the starting switch equipment for alternating-current self-starting converters. They are in addition to the converter panel.

The starting panels for the 600-volt converters often include equalizer and negative switches. When the relative location of the apparatus in the station is such that it is not desirable to run the equalizer and negative cables to the starting panel, a separate pedestal with proper equalizer and negative switches may be used.

Starting Switch.—These starting panels usually have mounted on them a 3-pole double-throw knife switch to connect the converter to low voltage for starting and full voltage for running as well as a 2-pole double-throw switch for field reversing in case machine comes up to speed with the incorrect polarity.

When the synchronous converter is used for 3-wire D.C. service an auxiliary blade is furnished on the starting switch and extra contacts furnished so that in the running position the neutral of the D.C. system is connected to the neutral point on the low tension windings of the various transformers. Figure 203 shows the connections of a typical synchronous converter installation for 3-wire D.C. service.

1500 Volt D.C.—Where the D.C. panels are intended for 1200–1500-volt service, the carbon breakers and knife switches are made distant control and the panels arranged as shown in Fig. 204. These panels are intended for use with two generators or converters operating in series and each panel consists of three sec-

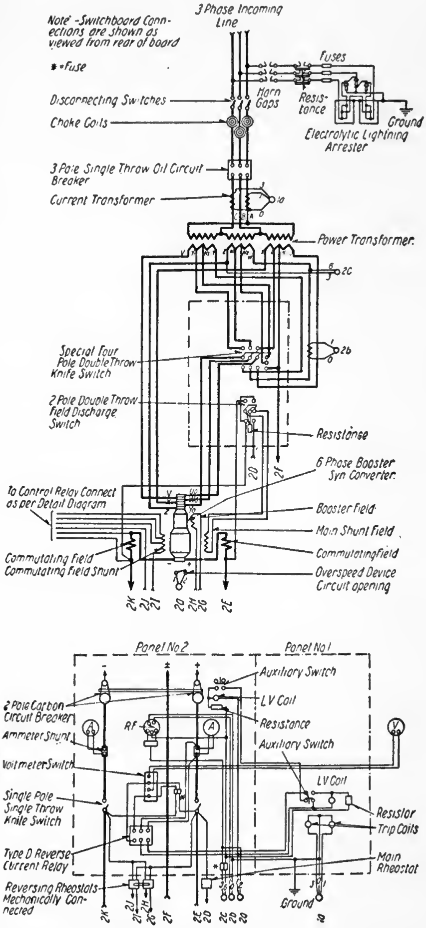


FIG. 203.—Diagram of connections for D.C. three-wire.

tions 2 inches thick with ½-inch bevels; the lower section is 25 inches high, the middle section 45 inches high, and the upper section 30 inches high. They are mounted on angle iron frame with channel iron base. The total height of the panel including the base is 102 inches. The barriers provided between the circuit breakers and at the ends extend 14 inches above the top of the panel. No high voltage live parts are mounted within 7 feet of the floor on the front of the panels.

The starting switch and the field discharge switch on the front of the starting panels are provided with barriers to protect against accidental contact with live parts.

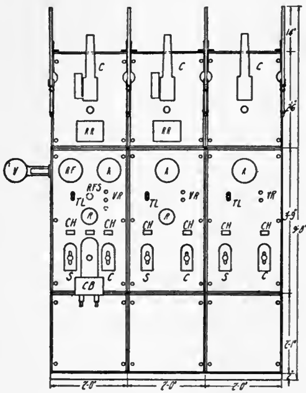


FIG. 204.—Switchboard for 1500-volt D.C. railway.

Meters.—The instruments included with these panels in the direct-current circuits have live parts insulated from the case for full voltage and cases grounded.

Reactive factor meters or power factor meters are supplied for synchronous converters as an aid in adjusting the field properly to keep down the losses in the machine armatures. These losses are less, the more nearly the synchronous converter operates at zero reactive factor.

The reactive factor meter is connected in the low voltage leads to the converter and not on the high voltage side of the step down transformers in order that it will indicate the true condition in the converter armature.

Synchronous motor panels are supplied with a main ammeter and a field ammeter for indicating proper machine operation.

Rheostats.—When two machines are connected in series for 1200-volt operation, their two rheostats are operated in tandem as one circuit from a single hand wheel. An insulated sprocket wheel is furnished on each rheostat so that the operating mechanism is insulated from live parts.

Circuit Breakers.—The positive circuit breakers are mounted on the front and at the top of the panels and are operated by closing and tripping handles located at a convenient height on the middle panel section. The circuit breakers trip free of the closing mechanism so that the speed of opening is the same as for direct operated breakers. The closing and tripping mechanisms are insulated from the breaker.

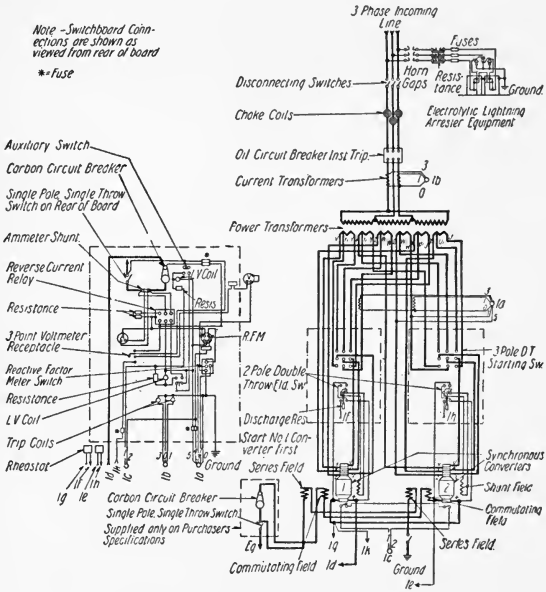


FIG. 205.—Diagram of connections for 1500-volt D.C. railway.

The installation of negative machine circuit breakers is optional. They provide additional protection against grounds caused by flash-over or insulation failure. In standard practice the circuit breakers in the alternating-current supply circuits are depended upon to provide this protection. The negative breakers are direct-operated, being located at a convenient height on pedestals. The moving parts of the negative breakers are dead when the breakers are open.

Switches.—The positive switches are mounted on bases on the rear of the panels, with Westinghouse construction, or on the front top section alongside of the circuit breaker for General Electric construction, the lowest point of live parts being at least 7 feet above the floor, and are operated from handles on the front, located at a convenient height and in line with the circuit-breaker handles. The operating mechanism is rigidly connected to the switch so that the position of the handle on the front is always a true indication whether the switches are open or closed.

Switches.—The switches for the negative side of the machine set are direct-operated. These are of the 600-volt type and are provided with barriers when connections are such that attendants would otherwise be exposed to a dangerous voltage. Negaive and equalizer apparatus may be omitted, if desired, when the station will have but a 1200-volt converter or generator set, as they are not essential for the operation of a single set. A negative main switch is convenient as a means of disconnecting the machine from the ground for insulation testing.

Connections.—Fig. 205 shows the connections of a typical substation for the control of a 13,200-volt 3-phase incoming line and two 6-phase synchronous converters, self-starting from the A.C. side and operating in series on the D.C. side for 1200–1500-volts D.C. railway service.

AUTOMATIC SUBSTATIONS

For many synchronous converter substations, particularly for interurban railway work, automatic operation has been adopted. Very complete and ingenious arrangements of apparatus have been worked out by the engineers of the General Electric Company and the Westinghouse Electric & Manufacturing Company. The first automatically controlled railway substation was equipped by the General Electric Company and placed in service during December, 1914, on the Elgin and Belvedere Electric Railway. The following description has been taken from a paper by Mr. Frank Peters, of the General Electric Company, presented before the Pittsburgh Meeting of the A.I.E.E., March 14, 1920.

G. E. Schemes.—The type of automatic equipments supplied by the General Electric Company consists of a group of relays, grid resistors and standard contactors, which together with a motor driven drum controller perform the usual function of starting, stopping and protecting the machines against irregularities without the aid of an attendant. In general, relays are used where the functions of starting, stopping and protecting the machines depend upon voltage, current or independent time values. During starting and stopping, however, numerous operations must be performed in a definite sequence, which if not strictly adhered to, is conducive to service interruptions.

Controller.—The motor driven drum controller is used to obtain this fixed time relation of events and to substitute, wherever possible, a type of contact more substantial than can be used with

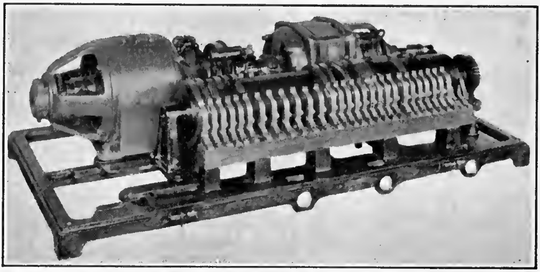


Fig. 206.—General Electric Co. motor driven controller for automatic substation.

relays. This device also includes a small D.C. generator which at the proper time during the starting operation separately excites the converter field, thereby definitely and immediately insuring the correct polarity.

Duties.—Protective devices having the following duties are provided to perform the functions ordinarily left to the discretion of the operator.

1. To limit the overloads.
2. To limit the temperatures.
3. To shut down the machine.
    (*a*) When A.C. or continuous D.C. short circuits occur.
    (*b*) Upon failure of alternating current.
    (*c*) Upon failure of any device.
    (*d*) In case of excessive speed.
    (*e*) Upon reversal of direct current.
4. To prevent machine starting.
    (*a*) During low A.C. voltage.
    (*b*) During single-phase A.C. supply.

Connections.—By referring to Fig. 207 which is a typical wiring diagram of an automatic 500-K.W. 600-volt equipment, the

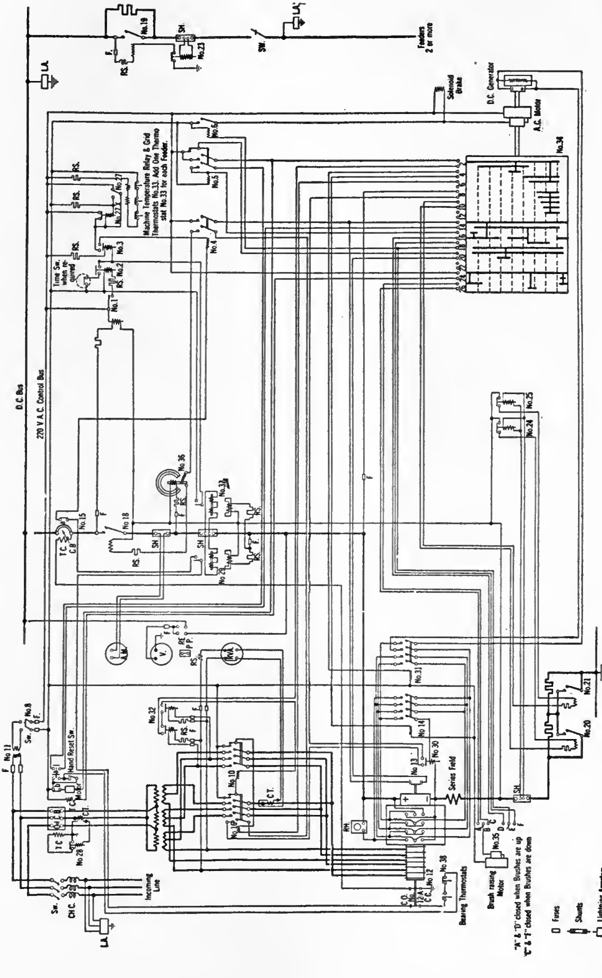


FIG. 207.—Diagram of connections G.E. automatic substation.

sequence of operation may be followed. For convenience of reference the principal devices have been numbered or otherwise labeled. It will be noted that the 220-volt A.C. control bus is continuously excited from the control transformer No. 11 and the operating coil of contact-making voltmeter No. 1 is always connected between trolley and ground.

Starting.—Assuming a particular station is shut down and a train is approaching. As it increases its distance from the next station on the line it will eventually cause the trolley voltage to drop and at a predetermined value, usually 450 volts, contact-making voltmeter No. 1 opens, de-energizing the operating coil of relay No. 2, which had been previously held open by excitation from the 220-volt A.C. control bus through relay No. 1. The closing of No. 2 closes relay No. 3 causing it to pick up and close contactor No. 4 provided the hand reset switch and contacts of A.C. low voltage relays No. 27 are closed. Relay No. 2 has a dashpot to prevent momentary fluctuation of low voltage from producing false operations of the machine. With the drum controller No. 34 in the "off" position as would be the case before the machine starts, contactor No. 4 completes a circuit through segments No. 13 and No. 16 on the drum controller and the limit switch of the brush-raising device which closes contactor No. 6, thereby starting rotation of the motor driven drum controller. Controller segment No. 15 soon closes contactor No. 5 which in turn energizes the motor operated oil switch mechanism causing the main converter transformers to become energized by the closing of oil circuit breaker No. 7. The operating coil connection of contactor No. 5 is then transferred from segment No. 15 to No. 14. This circuit passes through an auxiliary switch on the oil circuit breaker to insure the return of all devices to their normal position should the breaker open for any reason. When segment No. 2 makes contact, starting contactor No. 10 is closed connecting the converter to the low voltage taps provided the A.C. supply is delivering 3-phase current as determined by relay No. 32. Shortly the drum controller stops rotating because of the gap in segment No. 16 and waits if necessary for the converter to come up to speed. At approximately synchronism, speed-control switch No. 13 closes, bridging by aid of segment No. 20 the gap in segment No. 16, causing the controller again to start rotating so as to complete the function of connecting the machine to the line.

Next segment No. 3 closes contactor No. 31 connecting to the converter fields a 250-volt supply obtained from the small generator on the drum controller, thereby immediately ensuring proper polarity. Contactor No. 31 is then opened by segment No. 3 and the self-exciting field contactor No. 14 closed by segment No. 4 and running contactor No. 16 closed by segment No. 5 connecting the converter to normal secondary A.C. voltage. Starting and running contactors No. 10 and No. 16 are both mechanically and electrically interlocked with respect to one another to insure against accidentally short-circuiting a portion of the transformer secondary winding. Segment No. 26 next starts the motor operated brush rigging causing the converter brushes to be lowered, which completes the operation of preparing the machine for connection to the D.C. bus. Segment No. 7 is next energized with 600 volts direct current and shortly thereafter segment No. 8 closes the D.C. line contactor No. 18 whose control circuit is in series with converter field relay No. 30, polarized relay No. 36 and auxiliary switches on running contactor No. 16 and control contactor No. 4, thereby ensuring before closing No. 18 that the converter has proper polarity, correct field and full voltage A.C. running connections.

As soon as the line contactor closes the machine delivers load to the bus through the load limiting resistors which, however, are soon short-circuited by contactors No. 20 and No. 21 operated by segments No. 9 and No. 10. The drum controller is then stopped by segment No. 17. When connection to the bus is made through No. 18 the flow of current closes relay No. 37, which will cause relay No. 3 to remain closed regardless of relay No. 1 whose function started the station. In other words the control of the station is now dependent on the contacts of No. 37 which will remain closed so long as a predetermined current is being delivered to the bus. Should the current fall below a set value, relay No. 37 will open and cause relay No. 3 to drop out after a certain period of time and shut down the station. Relay No. 3 has a dashpot and is timed so that momentary low values of current causing No. 37 to open will not shut down the equipment.

Shutting Down.—When the station does shut down, relay No. 3 opens contactor No. 4 causing running contactor No. 16 and D.C. line contactor No. 18 to drop out and disconnect the machine. Contactor No. 5 opens after contactor No. 4 which operation establishes through an auxiliary contact a circuit to contactor No. 6, thereby starting the controller and running it to its "off" position. While doing this, however, segment No. 24 trips out the oil circuit breaker and segment No. 25 causes the converter brushes to be raised in preparation for starting upon the next load demand.

Overload.—In the event a heavy D.C. overload occurs, relay No. 24 will pick up and open contactor No. 20, thereby inserting resistance in the circuit. Should the overload increase to a greater value, relay No. 25 will operate and insert more resistance, and in stations not provided with individual feeder protection a third step of resistance is provided to limit still greater overload demands. The value of resistance used is such as to permit short circuit in the immediate vicinity of the station without injuring the machine. In some stations individual feeder protection, which consists of an overload relay No. 23, a contactor No. 19 and a resistor in each feeder circuit, is installed, thereby localizing to a degree the function of overload protection to each feeder. With such an arrangement only two sections of resistance are used in the machine circuit.

Overheating.—Protection from overheating the machine, its bearings and load limiting resistors is obtained by use of temperature relays No. 38 and No. 33 arranged to shut down the station immediately should such a condition arise.

Reversal.—A reversal of direct current is prevented by relay No. 29 and overspeed by speed-limit switch No. 12-A. Both of these devices necessarily operate a control circuit which immediately opens contactor No. 4 and shuts down the station. A shunt trip hand operated D.C. circuit breaker No. 15 is in series with No. 18 and only used to protect against the possibility of the line contactor freezing closed. Should this condition occur the converter would motor from the D.C. end upon the A.C. end being disconnected and the excessive speed resulting would trip the circuit breaker No. 15 through the operation of speed switch No. 12.

Short Circuit.—In case a short circuit occurs on the A.C. side of the equipment, the definite time limit overload relay No. 28 will trip out the main oil circuit breaker, shutting down the station and at the same time opening the hand reset switch which necessitates reclosing by hand before the station can be started again. This feature insures an inspector visiting the station to investigate the cause of the serious A.C. overload.

Low A.C. voltage relay No. 27 which is calibrated for a definite value, is connected so as not to permit the station to start, or to shut it down if running, should the high tension voltage become so low as to interfere with proper operation.

If for any reason a single-phase condition exists on the secondary side of the transformer during starting operations, relay No.

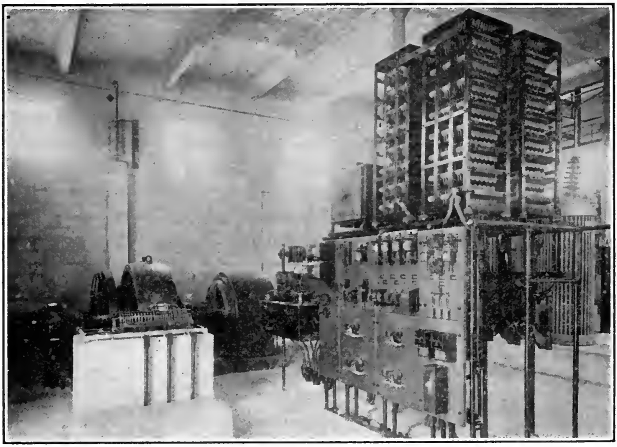


FIG. 208.—General Electric Co. automatic substation with M.G. set.

32 will lock out starting contactor No. 10 and prevent the converter from being connected to the transformer.

Polarized relay No. 36 protects against the possibility of the machine ever being connected to the line in the reverse direction. Unless proper polarity has been established before connecting the machine to the bus, line contactor No. 18 will not close.

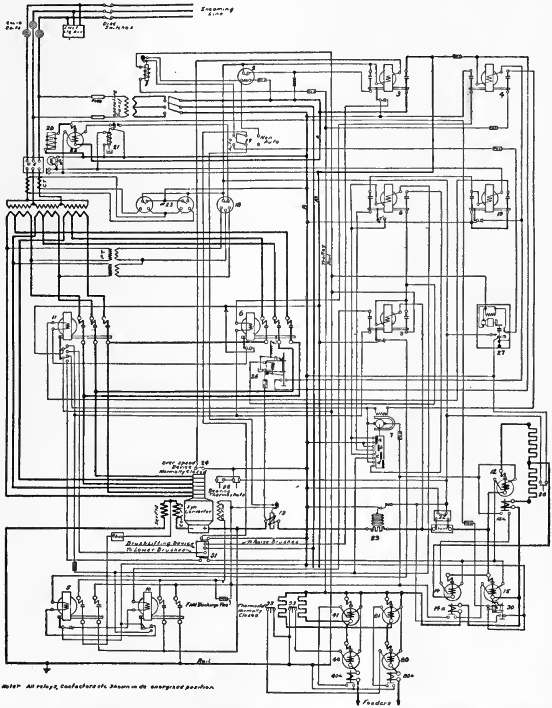
Motor Generator.—In stations containing a motor-generator set instead of a synchronous converter, certain modifications to the equipment are necessary to accommodate the starting operations, but the scheme of operation with few exceptions is similar to the converter equipments. Oil immersed starting and running contactors are used because of the higher transformer secondary voltage and a certain amount of overload protection is obtained by inserting one or two steps of resistance in the generator field circuit in addition to two steps of series resistance in the main D.C. circuit. This arrangement reduces initial cost since the field resistance and its contactors are of small capacity. An energy saving in resistor heat loss is also accomplished. The 250-volt generator on the drum controller becomes unnecessary in the case of a motor generator automatic equipment. See Fig. 208 for automatic substation with motor-generator set.

Westinghouse Schemes.—The automatic substation equipment of the Westinghouse Electric & Manufacturing Company has been designed to duplicate in every way the manual operation of substation apparatus without the attention of an operator. Starting and shutting down of the station are functions of the load demand. In addition, many protective devices uncommon to the average substation give absolute protection which is free from the human element. The schematic diagram Fig. 209 applies to equipment for standard alternating-current, self-starting synchronous converters up to and including 1500-kilowatt capacity, 750-volts direct-current. Referring to this diagram, the scheme of operation is as follows:

Starting.—A car or train enters the zone of a station which is at that instant idle. As the train approaches the station, the trolley voltage at the station is reduced. When the voltage falls to a predetermined value, for example to 75 per cent. of normal or below, contacts of a direct-current voltage relay (1) in the trolley circuit close, and as a result the coil of an alternating-current voltage relay (2) is energized, through an interlock on the brush lifting device (31), closed when brushes are raised from commutator. At the end of a definite time interval, which may be adjusted from instantaneous to five seconds, the contacts of this relay close. The time element prevents the station responding to momentary reductions in D.C. voltage, and in addition prevents the station from starting in case the A.C. voltage is abnormally low. The closed contacts of A.C.voltage relay (2) complete a circuit which closes the master relay (3) thereby energizing an auxiliary control bus 'A–2'. Relay(3) completes its own holding circuit, making further functioning of the control apparatus independent of trolley voltage.

Energizing of auxiliary control bus 'A-2' causes oil breaker (20) to close through the functioning of its control contactor (22).

The oil breaker in the closed position completes, through an interlock, the circuit for an alternating-current dashpot relay (21) which, when closed, de-energizes the oil breaker control



1 Undervoltage DC Relay
2 Low Voltage Delay AC Relay
3 AC Shunt Relay
4 AC Shunt Relay
5 Field Cont. (Norm. Fld.)
6 AC Starting Contactor
7 Polarised Motor Relay
8 AC Shunt Relay
9 DC Relay for Fld R'v'rs'l
10 Field Contactor (Reversed Fld.)
11 AC Running Contactor
12 DC Linn Switch
12a-14a Accelerat'g Relays
13 DC Ser Underl'd Relay
14-15 DC Bus Resistance Shunting Contactors
17 2 P.D.T. Knife Switch
18 Reverse Phase and Low Voltage AC Relay
19 AC Shunt Relay
20 Main Oil Switch
20a-Low Voltage Release
21 AC Dashpot Relay
22 Control Contactor for It. 20
23 AC Overload Relays
24 Overspeed Device
25 Bearing Thermostats
26 Field Reversal Limiting Relay
27 Underload Delay Relay
28 Grid Thermo. (Conv'rt'r)
29 Replica Thermal Relay
30 Lock-Out Relay
31 Brush-Lifting Device
32 DC Rev. Current Relay
33 Grid Thermostats (Feeders)
40-80 Feeder Contactors
41-81' DC Feeder Resist'nce Shunting Contactors

Fig. 209.—Diagram of connections Westinghouse automatic substation.

contactor (22). The oil breaker latches closed mechanically. In addition, bus 'A-2' energized, closes shunt relay (4) and field contactor (5). The closing of relay (4) in turn closes alternating-current machine starting contactor (6) which connects the converter to the starting taps of the power transformers. It will be noted that the closing of relay (4) and contactor (5) also completes the circuit for a polarized motor which drives a rotary switch (7) upon which is mounted four pairs of contacts, (7a), (7b), (7c) and (7d).

Rotary switch (7) is driven by a D.C. motor having a permanent magnet field in addition to the ordinary field winding. In starting, field coils of the motor are connected to trolley and rail, and the armature is connected to the D.C. brushes of the converter. Until the converter pulls into step, alternating current is delivered to the motor armature causing it to oscillate; when the converter is in step, direct current is delivered to the armature causing it to rotate in a direction dependent on the polarity of the converter. See Fig. 210.

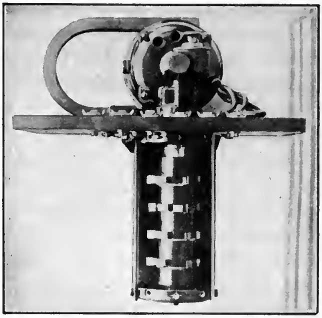


Fig. 210.—Westinghouse rotary drum switch for automatic substation.

Polarity.—Assuming incorrect polarity, the drum of (7) revolves in a counter clockwise direction. Relay (8) closes as contact (7a) is made, completes its own holding circuit and closes a contact in series with the coil of a direct-current relay (9) which closes when contact is made at (7d). This relay completes its own holding circuit, opens shunt field contactor (5) and closes reverse field contactor (10). Relay (8) is opened by the shorting of its coil, by an interlock closed when reverse field contactor (10) is closed, thus permitting the rotary switch to idle over the remaining contacts. The converter voltage on reverse field falls to zero thereby de-energizing direct-current relay (9) which in the open position causes reverse field contactor (10) to open, and normal field contactor (5) to again close. This operation corrects polarity under normal line conditions; however, should reverse polarity persist, the above operation will be once or twice repeated as may be necessary. In extreme cases, it is very difficult to correct polarity by field reversal, so, should the third attempt fail, relay (4) and in turn starting contactor (6) will be opened by the closing of the contacts of the field reversal limiting relay (26). This relay is a step by step device which operates each time the direct-current relay (9) closes, but is mechanically restored to first position when alternating-current starting contactor (6) opens. The alternating-current starting contactor (6) remains open for a short interval dependent on the time element of an air dashpot which at the end of its travel trips open the contacts of (26). Relay (4) now closes, in turn reclosing alternating-current starting contactor (6). One familiar with substation operation will appreciate that the above procedure automatically duplicates the work of an operator correcting for reversed polarity.

Assuming correct polarity, drum switch (7) rotates in a clockwise direction. Relay (8) closes as contact is made at (7a), completes its own holding circuit and closes contacts in series with shunt relay (19) which closes when contact is made at (7b). Relay (19) closed, forms its own holding circuit, opens relay (4) which in turn opens alternating-current contactor (6). The closing of relay (19) and the opening of contactor (6) closes alternating-current running contactor (11) thereby connecting the converter with correct polarity to the full voltage A.C. circuit. Interlocks opened by the closing of (11) de-energize the polarized motor relay (7).

The alternating-current running contactor (11) in the closed position, through the closing of an interlock, energizes the brush lifting device (31) by which the direct-current brushes are lowered into position on the converter commutator. An interlock on (31), closed when brushes are in the running position, completes, through an interlock on the alternating-current running contactor (11), a circuit which closes the direct-current line switch (12) thus connecting the converter to the trolley through resistance proportioned to limit the current in the machine to approximately 150 per cent. of its rated full-load capacity. Resistance shunting contactors (14) and (15) are closed by the direct-current accelerating relays (12a) and (14a) should normal load not be exceeded.

Feeders.—Feeder contactors (40)–(80) are normally closed, the operating coils being energized from the trolley circuit. Feeder resistance shunting contactors (80)–(81) open and close dependent on current setting of D.C. series relays (40a)–(80a).

Assuming overload on feeder (41), series relay (40a) will open contactor (41) thereby inserting resistance in series with the feeder. Should the overload be severe and last for some length of time, heat from the series resistance will open the contacts of thermostat (33) thus opening contactor (40), thereby isolating the feeder until the resistance cools to a point which will allow the contacts of thermostat (33) to again close. If the sum of the feeder loads through resistances is in excess of the safe load of the converter, resistance shunting contactors (14) and (15) also open through similar action of (12a) and (14a).

When all resistance is cut out of the circuit, the trolley voltage at the station rises to a point which will open the contacts of voltage relay (1). However, since the master relay (3) maintains its own holding circuit, no action results from fluctuations of the direct-current voltage.

Shutting Down.—Shutting down of the station is dependent on the position of series underload relay (13). When the load on the converter falls to or below a predetermined value, the contacts of this relay close, thereby starting the underload delay relay (27).

Relays.—Underload delay relay (27) consists of a direct-current motor driving, through a train of gears and a magnetic clutch, a vertical shaft mounting a small arm which, at the end of its travel, closes a pair of contacts short-circuiting the coil of the master relay (3), causing it to drop out, thus de-energizing the auxiliary control bus 'A-2' and thereby opening all alternating-current and direct-current contactors. The master relay in the open position closes an interlock which energizes the brush lifting device (31) and the brushes are raised from the commutator to the starting position. Should load be demanded from the station before the contacts of underload delay relay (27) are closed, the opening of the contacts of series relay (13) de-energizes the motor and magnetic clutch in series with it. The shaft releases and is returned to its starting position by means of a small coiled spring, thus assuring a very definite no-load period. Any time element desired between the limits of 3-and 30-minutes may be secured by simple adjustments.

Reverse-phase starting and single-phase starting are prevented by the closing of the contacts of reverse phase and low voltage relay (18) which short-circuits the coil of the master relay (3).

Low Voltage.—If the alternating current line voltage is too low for satisfactory operation, relay (2) will not operate and the contacts of relay (18) close, as stated in the above paragraph, either of which prevents the station from starting. Should low voltage occur while the station is in operation, the contacts of relay (18) close.

Direct-Current Overload.—Various sections of the current limiting resistor are inserted in the machine circuits by contactors (14) and (15), when loads exceed the setting of the overload trip on the contactors. When the current values are within the overload setting of the contactors, they again reclose. Overload settings of the switches and the ohmic value of the resistor sections are dependent upon the particular application.

Temperature.—Thermostats are placed in the machine bearings and in each resistor section. Should an overload persist to the extent of overheating a section of the resistor, or should a machine bearing reach a dangerous temperature, the station will be shut down by the short-circuiting of the coil of master relay (3). When the resistor temperature returns to normal the station comes back on the line, unless prevented by the setting of lockout relay (30). However, the station once shut down due to an overheated bearing can only be restored to service by resetting the thermostat contacts by hand.

In order to take the maximum advantage of the overload capacity of the synchronous converter, the current limiting devices are usually set to correspond to the momentary overload rating, while a Replica Thermal Relay protects against sustained or repeated overloads. This device is essentially a thermostat having a temperature characteristic similar to that of the machine which it protects and is heated by a current proportional to that in the converter armature. As the armature conductors approach a dangerous temperature, the thermostat contacts close, shunting the coil of master relay (3), thereby shutting down the station until the apparatus has cooled.

Alternating-Current Overload.—Should trouble develop between the high tension side of the power transformers and the direct-current limiting resistor, protection is obtained by the operation of alternating-current overload relays (23) which short-circuit the coil of master relay (3) thereby shutting down the station.

Polarity.—The fact that the polarized motor relay (7) must rotate in a clockwise direction, in order to establish the proper sequence of operations, insures the machines coming onto the line with correct polarity.

Reverse Current.—The equipment includes the usual direct-current reverse-current relay (32) which, when the contacts are closed, short-circuits the coil of master relay (3) thus shutting down the station.

Overspeed.—The usual speed limit device (24) mounted on the converter, furnishes protection from overspeed by opening master relay (3).

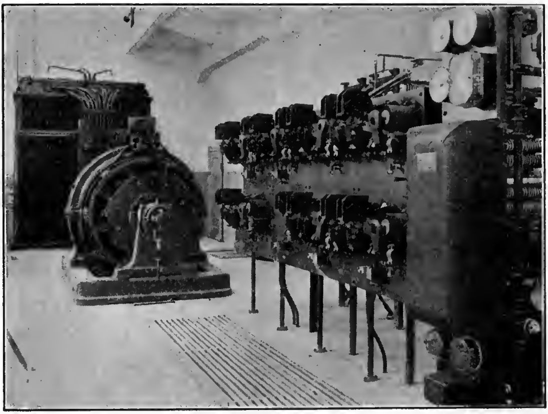


Fig. 211.—Westinghouse automatic substation.

Thermostat.—Liquid thermostats of the copper bellows type are placed in the machine bearings and in each resistor section. The converter bearings are so arranged that the operating element of the thermostats is embedded in the bearing shell. Thermostats of this type are very rugged and operate very satisfactorily throughout wide ranges of temperature.

Lockout Feature.—This feature is provided by a notchup relay (30) which operates each time the main oil switch closes and is reset to zero position by the closing direct-current contactor (15). If the oil breaker closes three times before the direct-current contactor (15) is closed, the contacts of relay (30) close, short-circuiting the coil of the master relay (3) thus locking out the station until the trouble has been remedied and relay(30) reset by hand.

Continuous Running.—If the 2-pole double-throw switch (17) is thrown to the right, the underload delay relay (27) is out of circuit and the station will start and run continuously but with all automatic protective features. A typical automatic substation arrangement is shown in Fig. 211.

PORTABLE SUBSTATIONS

In connection with many railway systems employing synchronous converters it is frequently advisable to have a synchronous

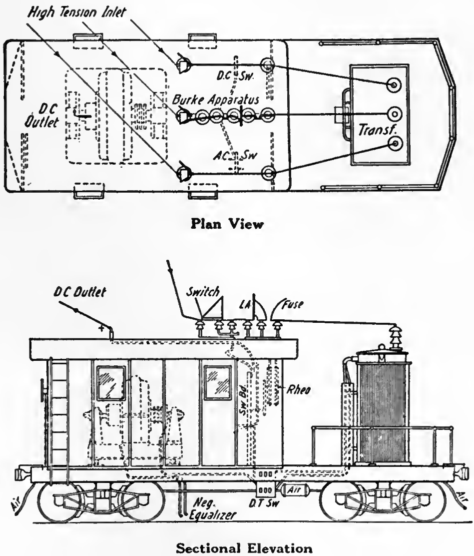


Fig. 212.—Sectional view of portable substation.

converter with its transformer and switchboard equipment placed in a suitable car so that it can be moved from one part of the system to another wherever there is an extra demand for current that cannot be taken care of by the nearest substation. Owing to the low head room in a car and the necessity for compact and simple equipment, the standard synchronous converter equipment has been modified utilizing small panels but providing all necessary control and metering equipment except that for the high voltage side of the step down transformers.

They are designed for 300-K.W. and 500-K.W. 25-cycle and 60-cycle, 6-phase synchronous converters, which are self-starting from the alternating-current side.

The panels are 1½ inches thick with ⅜-inch bevels, mounted on angle iron framework extended for bracing to the roof of the car.

The circuit breaker, knife switch, and instrument equipment for the low voltage alternating-current and the direct-current sides of the converter is the same as previously outlined, except that the alternating-current starting knife switch is hand operated, remote control, for mounting under the car.

Air-break switches having low voltage trip and fuses are used for protecting the step down transformers and the converter. The switch is operated from a handle on the panel and is interlocked electrically with the direct-current circuit breaker so that the latter is opened when the former trips. Fig. 212 shows a sectional view of a portable substation.

ELECTRICALLY OPERATED D.C. SWITCHBOARDS

Field & Exciter.—While electrical operation is fairly common for high voltage A.C. boards using oil circuit breakers it is not used so frequently for D.C. or low voltage A.C. with carbon breakers but there are some cases where it is also used to advantage for low tension A.C. or D.C. service using carbon circuit breakers. Probably the place where electrical operation is used most frequently for D.C. service is for the control of exciters and field circuits in a generating station where electrical control is employed for the main A.C. circuits and the exciter and field circuits are electrically controlled from the generator switchboard.

Rio de Janeiro.—Where the distance from the switchboard to the field switches and field rheostats is great, it frequently becomes advisable to operate these devices electrically. These are frequently combined to form a switchboard like that shown in Fig. 213 which was supplied by the Westinghouse Electric and Manufacturing Company to control the field circuits of six 5000-

K.V.A. generators and the field and armature circuits of three 200-K.W. 250-volt exciters. Each exciter is provided with two 800-ampere, 3-pole, solenoid operated carbon breakers for connecting to either or both of two sets of direct-current bus bars, one of which is used for light and power service, and the other for excitation. The generator panels are provided with 2-pole, solenoid operated field switches and motor operated field rheostats.

Fig. 213.—Field & exciter switchboard for Rio de Janeiro.

Rheostats.—The motor operated field rheostat faceplate used in this plant is provided with a clutch, so that in case of trouble to the motor the faceplate may be operated by hand after disengaging the clutch. With this faceplate a signal switch is provided to actuate a lamp on the switchboard when the arm is bridging two contacts. This faceplate is also provided with a limit switch that opens up the motor circuit when the arm has reached the limit of its travel in either direction, and the connections are so made that while the motor can no longer be operated in one direction it can be run in the opposite direction.

Inawashiro.—In certain cases it is preferable to mount the electrically operated field rheostats entirely independent of the field switchboard which is then reserved exclusively for the exciter breakers and the generator field switch equipment as shown in Fig. 214, which shows the exciter and field switchboard furnished by the Westinghouse Company for the Inawashiro Hydro Electric Company of Japan, for the control of four 200-K.W. 250 volt exciters and the field circuits of the six 7700-K.V.A. generators.

This switchboard comprises six panels of marine finished slate mounted on a self-supporting pipe framework with the back of the board completely enclosed by an open mesh grill with locked doors at each end.

The two panels for the field circuits of the generators each contain six 2-pole solenoid operated field discharge switches used in pairs for connecting the field circuits of three generators to either of the two sets of field bus bars. These field switches are electrically interlocked in pairs in such a way that only one of a pair can be closed at a time.

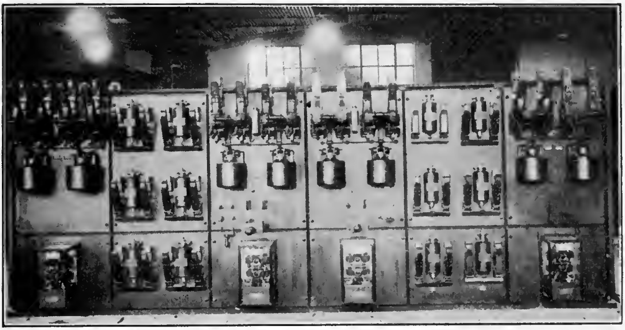


Fig. 214.—Field & exciter switchboard for Inawashiro.

The four remaining panels which control the armature circuits of the exciters each contain two 2-pole solenoid operated carbon break circuit breakers provided with overload and reverse-current definite time limit relays so arranged that any exciter can be connected to either of the two sets of busses and the breakers are interlocked so that the exciter can only be connected to one bus at a time.

HEAVY D.C. ELECTRICALLY OPERATED BOARDS

Aluminum Company of America.—As an example of electrical control applied to heavy capacity low voltage service, Fig. 215 shows the interior of the Marysville station of the Aluminum Company of America containing nine 2500-K.W. 550-volt rotary converters. The control desk may be noticed in the rear of the station on the switchboard gallery and this contains the necessary controllers and meters for the various circuits.

One of the nine synchronous converters is a spare while the remaining eight are operated in two groups of four each in parallel on the D.C. end and on the A.C. end are fed from four sets of secondary leads from the same transformer bank. The low tension A.C. leads are brought in from the transformers through the right-hand wall. Three of the six phases run direct to the synchronous convetrers while the remaining three pass through the 2500 amperes 3-pole solenoid operated carbon breaker near the right hand-wall. The synchronous converters are started from the D. C. end and synchronized before being thrown in on the A.C. end. For starting after a complete shut down an A.C. starting motor is provided for starting either of two synchronous converters these in turn furnish the direct current for starting the others.

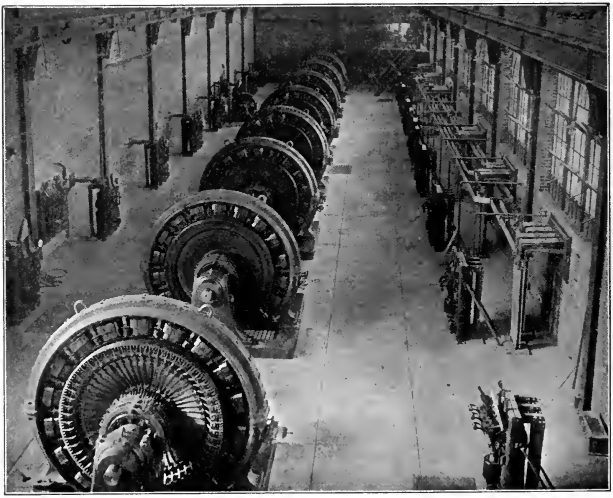


FIG. 215.—Marysville station of Aluminum Co. of America.

The spare rotary can be operated from any of the windings of either of the two transformer banks in place of a rotary that is out of commission and there is a spare transformer that can be used in place of any of the six regular transformers.

For the D.C. end of each rotary two 5000-ampere solenoid operated carbon breakers are furnished and a 20,000-ampere breaker is supplied in the outgoing feeder fed from four synchronous converters in parallel.

G. E. Installations.—A number of large electrically operated carbon break circuit-breaker outfits were supplied by the General Electric Company for the substations of the Interborough and Metropolitan System in New York City and to other plants in different places.

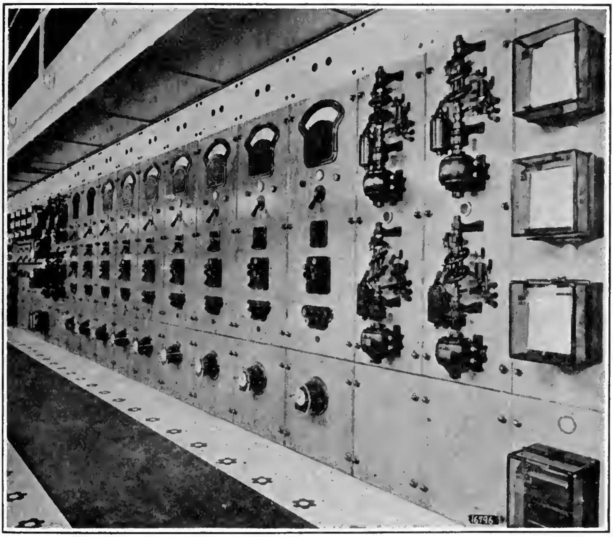


FIG. 216.

There are also numerous installations of electrically operated carbon circuit breakers furnished by other builders for steel mill service and large industrial plants.

I. T. E.-Ford Plant.—One of the most interesting installations of I. T .E . circuit breakers, both hand and electrically operated in a very large capacity, direct-current installation, is at the plant of the Ford Motor Company, in Detroit, where there are fourteen 3750-K.W., one 2500-K.W. and one 1000-K.W. 250-volt D.C.

generators connecting to two 250-volt D.C. busses and supplying energy to a large number of D.C. feeders.

Main Control Board.—A partial view of the main switchboard showing the generator control panels is given in Fig. 216. The panel at the extreme right-hand end contains graphic instruments, the next two panels gyrostatic voltage balance detectors, the next panels being generator control panels with flush mounted illuminated dial Weston ammeters, Sangamo watt-hour meters and special control switches used with the generator breakers, signals, etc. Then there are more panels with gyrostatic balancers, graphic meters, control circuits, etc. The other end of the switchboard controls D.C feeders with 2-pole carbon breakers at the top, round pattern flush mounted Weston ammeters, and 2-pole double-throw knife switches so arranged that the feeders can be connected to either of the two sets of bus bars. On the gallery above are located additional feeder panels.

Signals.—To facilitate the operation of the plant by the switchboard attendant, a complete system of signals is provided between each engine and the control section of the switchboard. On the signal board is mounted an ammeter indicating the generator current, two voltmeters showing the voltage on the respective sides of the 3-wire ignition circuit, a switch for completing the ignition circuit independent of the auxiliary switch associated with the generator circuit breaker, and four signalling switches. With each switch is associated a signal lamp having a distinctively colored bull's eye lens. At the switchboard is installed an identical set of lamps so that the signal given by the engineer lights the corresponding lamp at the signal board as well as the switchboard, and at the latter point a bell is also rung in order to insure the prompt attention of the operator.

Circuit Breakers.—Those controlling the respective generators are of the type shown in Fig. 217, these being triple-pole double-throw controlling the positive, negative and equalizer leads and providing alternative connections with either of the two sets of busses. They are equipped with direct-acting overload time limit features in each main lead, and with reverse-current trip in the negative lead, thus insuring the generators against short circuit or unduly sustained overloads and also against motoring.

Mechanism.—The remote control mechanisms are operated by means of motors, there being one of these mechanisms for each pole. Directly associated with these are interlocking devices so arranged that the poles of the circuit breaker may be closed only in predetermined sequence; *i.e.*, equalizer first, then positive and finally the negative pole. When the circuit breaker is in the full open position, positive and negative switch members of both throws are locked out, and only the equalizer members are free

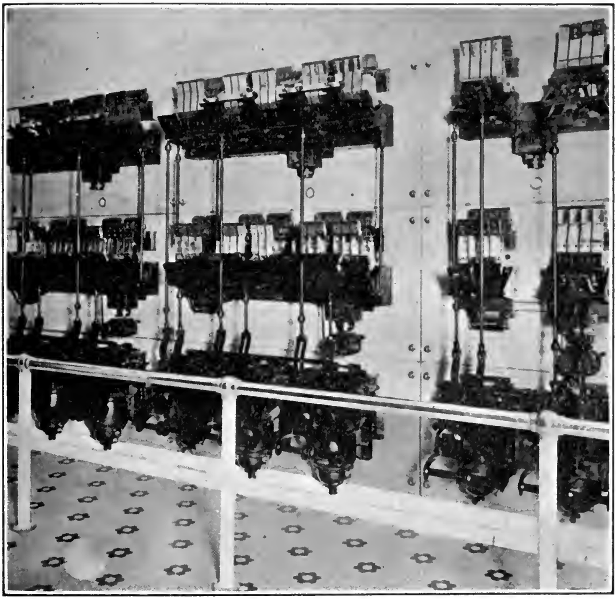


Fig. 217.

to be moved to the closed position. Whichever throw of the equalizer is closed, the other is thereupon locked open, while the positive pole which corresponds with the closed equalizer pole is at the same time unlocked. The subsequent closing of this member unlocks the corresponding negative pole. The interlocks above referred to are mechanical and are effective whether the apparatus is operated electrically or by hand.

Synchronous Converter Starting.—Another rather special arrangement of motor operated double-throw carbon break circuit breaker is shown in Fig. 218, this illustrating the starting and running switch for use with a 2000-K.W. booster converter. This starting switch consists of a 3-pole, two step arrangement for the purpose of applying first, low voltage, and then full voltage to the alternating-current end of the rotary. The three upper poles

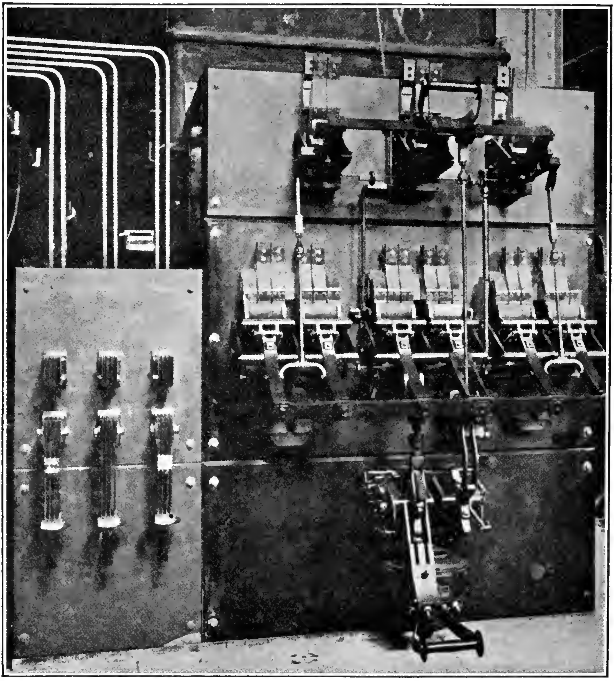


Fig. 218.

which operate as a unit, carry the starting current which is supplied at 93 volts, 60 cycles and reaches 9250 amperes as a maximum. These poles are amply capable of rupturing this current in the event of failure of the synchronous converters to start. The three lower poles which also operate as a unit carry the running current which may attain a maximum of 5500 amperes, the voltage being 193.

Both starting and running elements of the switch are arranged for either hand or remote control and the two elements are so interlocked both mechanically and electrically as to insure proper sequence of operation under any and all conditions. The construction is such that it is impossible to close the starting switch unless the running switch is opened. The preliminary movement of the running switch for the closed position causes the immediate opening of the starting switch so that the arc on this switch is broken before the circuit is established for the running switch.

As further protection against the improper application of full potential to the synchronous converters an induction relay is provided which locks the running switch in the open position until the rotary is running at very near synchronism. This induction relay is so sensitive in its operation that it may readily be adapted to release the running switch only when the synchronous converters is half cycle or less per second out of synchronism.

CHAPTER XIV

HAND OPERATED A.C. SWITCHBOARDS

EXCITER PANELS

As practically all A.C. switchboards have to take care of the exciters as well as the A.C. generators and the feeder circuits, the exciter panels can really be considered as part of an A.C. switchboard and are made to line up in general arrangement with the A.C. board. The panels for the control of the exciters used with alternating-current generators are essentially the same as other 2-wire direct-current generator panels except that no automatic protection is provided. Panels are suitable for generator voltage regulators, either with or without control for motor driven exciters. They are designed to match and form part of the standard alternating-current switchboards.

Limits.—The capacity of a single exciter circuit is usually limited to 300 amperes for the 48-inch panels and 1600 amperes for the 90-inch panels.

Protection.—Standard practice in supplying switchboard apparatus for control of exciter circuits is to furnish non-automatic switching devices. Where the exciters are driven by alternating-current motors, the automatic circuit breaker in the motor supply will be furnished with a high overload setting.

This practice is in harmony with the Rules and Requirements of the National Electrical Code and is justified both because contrary practice would jeopardize the continuity of the alternating-current service, and because modern exciting apparatus is very reliable.

However, if special conditions make it necessary to provide automatic protection in an exciter circuit, the builders are prepared to supply suitable devices even though at variance with their usual recommendations and practice.

Field Discharge.—It should be noted that any device to open a live field circuit must be provided with a field discharge resistance, as otherwise the opening of such a circuit may induce a voltage in the field windings tending to puncture the insulation.

In some cases with parallel-operated exciters it may be desirable to provide automatic devices that operate only on reversal of energy in an exciter circuit, in order to disconnect a defective exciter. In such cases standard generator panels having automatic circuit breakers may be used by omitting the overload feature on the breakers and adding the necessary reverse-current devices.

Connections.—Fig. 219 shows typical connections for a steam driven exciter, a motor operated exciter, a voltage regulator and

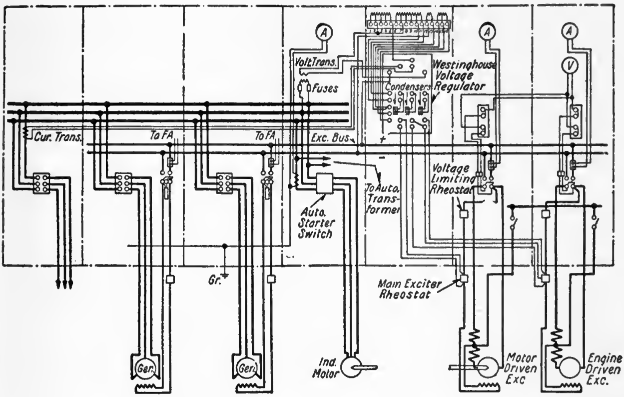


FIG. 219.—Typical connection exciter and field connections.

the field circuits of two generators. The usual equipment for an exciter comprises a 3-pole switch or a 2-pole main switch and a single-pole equalizer switch with an ammeter, a voltmeter switch and a field rheostat for the main exciter circuit as well as one for use with the exciter voltage regulator. One voltmeter takes care of two or more exciters.

A.C. SWITCHBOARDS WITH KNIFE SWITCHES

For moderate voltage installations in industrial plants and small central and distributing stations where voltages do not exceed 480 volts, panels with knife switches and enclosed fuses can be used where the cost of a switchboard with oil circuit breakers is not justified. Enclosed fuses must not be supplied under conditions where the available current on short circuits exceeds the limits fixed by the National Electrical Code.

Limits.—The capacity of a single generator panel is usually limited to 1000 amperes, a single feeder circuit to 600 amperes, and a complete switchboard composed of these panels to 2000 amperes in any section of the bus bars. Where the total capacity exceeds 2000 amperes the panels should be arranged with the feeders and generators interleaved in such a way that no part of the bus will have to carry more than 2000 amperes.

Voltage Readings.—With the apparatus supplied on the generator panels and with the bus instrument equipments, provision is made for the indication of voltage on one phase of the bus and on any phase of the machine. Provision can be made for indication of voltage on any phase of the bus and on one phase of the machine. Synchronizing is done between bus and machine by means of a synchronoscope.

If a sectionalized bus is used, a voltmeter switch is needed to transfer the bus voltmeter to either section of the bus. The bus instrument equipments include lamps for mounting on the panels for continuous ground indication.

Generator panels include drilling for remote-control rheostat mechanism, but the mechanism is not included as part of the switchboard. No automatic overload protection for the generator armature or field circuits is supplied. Enclosed fuses provide automatic overload protection for the feeder circuits.

Switches.—Round stud knife switches without quick break attachments are furnished with standard panels. When circuits must be frequently opened under load, quick break switches are recommended for 100 amperes and above.

Blank Panels.—It is desirable to install blank panels in cases where the future equipment cannot be placed at either end of the board. Such provision at the time of the original installation makes it unnecessary to move existing panels and connecting conductors at the time of making additions.

Panels with single-throw switches, for operating with a single bus system only, are usual. Panels with double-throw switches for operating with a double-bus system can be supplied. Ordinarily, for plants of moderate capacity the sectionalizing of the lighting load and the power load may be obtained by grouping all the lighting circuits on one section of the bus and the power circuits on the other section, the two sections being connected together, when desired, by a switch. This permits carrying all the load with one machine during light-load periods.

A.C. SWITCHBOARDS WITH OIL CIRCUIT BREAKERS

For higher voltages and in many cases for moderate voltages it is advisable to utilize oil circuit breakers and these may be mounted directly on the rear of the switchboard or made distant control operated mechanically or electrically depending on various circumstances. The general appearance of the A.C. panel switchboards is largely influenced by the type of instruments used and by the cover plate or control device employed with the oil circuit breakers.

These switchboards are designed to control the alternating-current electrical equipment of central and distributing stations and industrial plants.

Direct-control.—These boards are designed for plants not exceeding 3000-kilovolt-amperes capacity, requiring panels not exceeding 800 amperes capacity, where the voltage is not over 2400 and where it is not so advantageous to locate the oil switching devices apart from the panels.

Hand Remote Control.—These switchboards are applicable where the simplicity of connections or accessibility desired cannot be obtained with panel mounted apparatus, where station capacity of voltage is so high as to make it desirable to mount switching equipment apart from panels, and where station arrangement permits the use of manually operated remote control oil circuit breakers.

Electrical Remote Control.—These switchboards are applicable where the equipment must be remote controlled but where manually operated switchboard apparatus is not suitable.

Accessibility.—To make the rear of the switchboard more accessible, all the current transformers are usually furnished for mounting apart from the panels, and arrangements should be made for mounting these transformers in the main leads in the most suitable location. Voltage transformers will usually be mounted on the rear of panels, as this location is advisable in order to get the advantage of short primary leads and ready access to primary fuses. This applies chiefly to direct-control switchboards.

Panel Frame Mounting.—Additional advantages in construction can often be obtained by the use of breakers mounted on panel framework. Usually oil circuit breakers, both non-automatic and automatic, can be supplied for mounting on horizontal pipes attached to the panel framework back of the operating handle, as shown in Fig. 220. In general, the panel frame mounting gives a better construction, in that connections from circuit-breakers to bus bars are more nearly direct and more space is available for taking away connecting cables to panels and for mounting switchboard details. Some of the other advantages are the following: less likelihood of oil getting on panels; the weight of breakers is carried on frame instead of on panel; the rear of the panels is more accessible; several types and capacities of breakers have interchangeable mountings; with narrow panels the position of the breaker handle is not restricted to the center of the panel so that knife switches and handles for remote control breakers can often be added where this would be impossible with direct panel mounting unless wider panels are used.

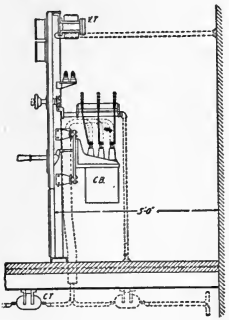


Fig. 220.—Switchboard with panel frame mounted breakers.

Voltage Readings.—With apparatus supplied on the generator panels and with the usual bus instrument equipments, provision is made for reading the voltage on one phase of the bus and on any phase of the machine for 240, 480, and 600-volt systems, when voltmeters are wound for primary voltage; and for reading the voltage on any phase of the bus and on one phase of the machine on systems of higher voltage, or in cases where voltmeters are wound for secondary voltage on systems of 600 volts and under. Synchronizing is done between bus and machine by means of a synchronoscope.

If the voltage indication on all three phases on the machine side of the generator circuit breaker is desired for panels having secondary voltage instruments, it is necessary to supply with each generator panel a 3-phase voltmeter switch, and an additional voltage transformer.

Meter Equipment.—Direct-control switchboard equipments include power factor meters, wattmeters, and watt-hour meters with windings for bus voltage for 240 and 480 volts, and voltmeters and frequency meters with coils for bus voltages for 240, 480 and 600 volts. For bus voltages above these values, voltage transformers are required. Synchronoscopes require voltage transformers for all voltages above 115 (nominal).

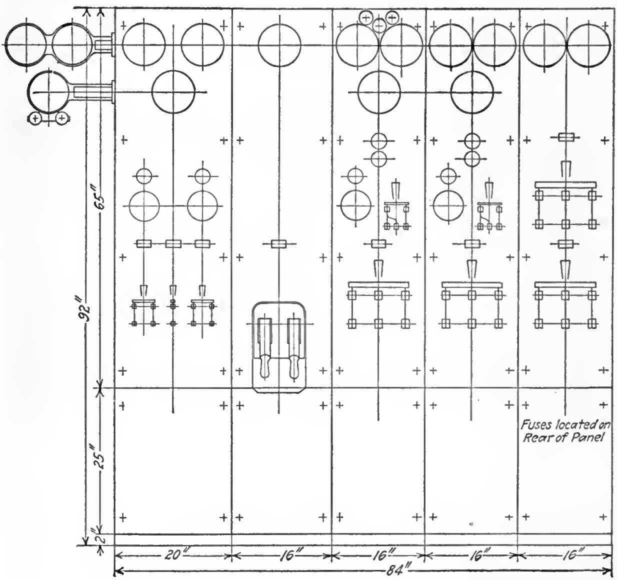


FIG. 221.—Typical low voltage Westinghouse switchboard.

The question of the arrangement of circuit breakers and bus bars will be considered later and a few typical examples of General Electric and Westinghouse panel boards will be given to illustrate the principal features of design.

Westinghouse Switchboards.—Fig. 221 shows a typical low voltage A.C. Westinghouse switchboard for the control of two exciters, one exciter motor, two generators and two feeders. On swinging brackets are placed two voltmeters, one connected to the bus and the other plugging on any generator, and a synchronoscope with two synchronizing lamps.

The double exciter panel contains two 2-pole exciter main switches, one single-pole equalizer switch, two exciter ammeters with one voltmeter and voltmeter switches for connecting it to either exciter. The next panel for the exciter motor contains the handle for the auto starter and an ammeter.

Each generator panel contains an A.C. ammeter with three-way switch to connect it to any phase, a polyphase indicating wattmeter, a field ammeter, voltmeter and synchronizing switches, field rheostat and field discharge switch with resistor and main 3-pole knife switch.

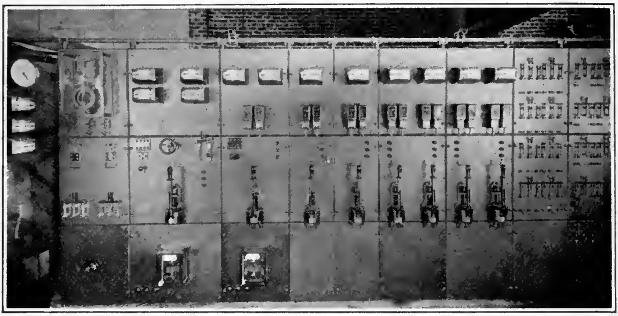


FIG. 222.—Panel switchboard, hand operated breakers—General Electric Co.

G. E. Panel Board.—Figure 222 shows a typical General Electric switchboard supplied to the Catton, Neill & Co., Ltd., of Honolulu, H. I. This board controls two exciters, one 480 volt 3 phase 3 wire A.C. generator, one 480 volt 3 phase 3 wire incoming line, six 480 volt 3 phase 3 wire power feeders and various lighting feeders. The synchronoscope, exciter voltmeter, etc., are mounted on swinging panel adjoining exciter panel. The three phase generator panel is provided with horizontal edgewise A.C. ammeter, voltmeter, indicating wattmeter and field ammeter, field rheostat, field switch with discharge clips, voltmeter and synchronizing receptacles, non-automatic generator main switch, watthour meter and testing receptacles. The next panel is the incoming line panel and is provided with indicating meters, voltmeter and synchronizing receptacles, ammeter plug receptacles, plunger type overload relays, automatic oil circuit breaker, watthour meter and calibrating receptacles. The next four panels are power feeder panels controlling a total of six circuits and each circuit is provided with the following:

Ammeter
Ammeter plug receptacles
Ammeter plunger type overload relays and automatic oil circuit breaker.

The panels at extreme right hand end of switchboard control various lighting circuits, each circuit provided with a 3 pole knife switch properly fused.

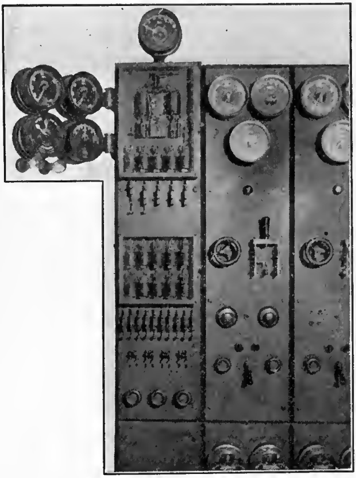


Fig. 223.—Electrically operated switchboard round meters.

Electric Operated Switchboard.—Fig. 223 shows a typical panel switchboard using 7-inch diameter black dial round pattern instruments with distant electrical control oil circuit breakers. The swinging bracket contains the bus voltmeter, the machine voltmeter, the exciter voltmeter and the synchronoscope with two synchronizing lamps. The first panel on the left contains the voltage regulator for three exciters not operating in parallel and contains the various relays, rheostats, switches, etc., needed for the regulating equipment. Each of the next three panels controls a generator with its direct connected exciter. Each panel is provided with an ammeter with three way ammeter switch, a polyphase indicating wattmeter, a field ammeter, an exciter rheostat, field switch with discharge resistor, a voltmeter and synchronizing receptacle, a control switch for the motor operated generator rheostat, a control switch for the governor motor, a control switch with indicating lamps for use with the electrically operated breaker in the generator circuit, two single-phase overload relays and a watthour meter. The remaining panels are feeder panels, one of them containing a graphic wattmeter.

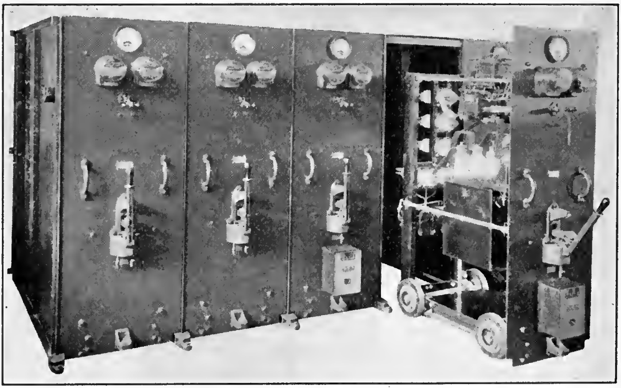


Fig. 224.—G.E. truck type switchboard front view.

Truck Type.—One of the latest developments in the way of A.C. panel switchboards is the truck type of design shown in Fig. 224 in front view with one of the trucks withdrawn, and in side view Fig. 225. This type of switchboard is made up of removable truck type panels and can be supplied in separate units or built up to form a complete switchboard with its accessories. Connections are automatically broken as soon as the truck is removed from the compartment, positively insuring that workmen have no live parts to handle. One great advantage is obtained in that continuity of service is assured. Should a breakdown occur, a spare unit can immediately be placed in service without taking the power off the main bus thereby interrupting the service on other sections of switchboard. This gives great flexibility to the station.

Limits.—These panels can be supplied for voltages up to 7500 and current-carrying capacity up to 800 amperes; also in various combinations of oil circuit breaker, instrument transformers and meters.

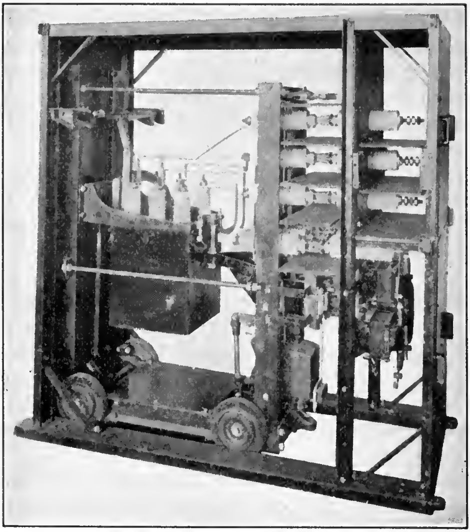


Fig. 225.—G.E. truck type switchboard, side view.

Construction.—The general construction of the complete panel is shown. All H. T. bus bars and cable connections are carried on substantial porcelain insulators mounted in the frame supports which are built up to form a complete cell structure. The framework is so designed that a new panel can be added at any time, the complete structure being finished off by cover plates bolted to the ends of the bus bar chamber, except in cases where cables are to be connected direct to the bus bars. In such cases a cable box can be fitted to the opening at the end of the bus bar chamber. Horizontal partitions are fitted above and below the bus bars so that the latter are enclosed in a separate and continuous chamber. Where space is available behind the panel, access can be obtained to these chambers by removing the back and top covers. Where space is limited, however, the complete cell structure can be built against the wall, access to the back being obtained through the hand holes provided.

Covers.—Protecting covers for cables and bus bar terminals can be supplied, so that when it is necessary for work to be done in a cell, while the terminals are alive, these covers can be padlocked in position and the work can be done with perfect safety. Portable cell doors can also be supplied for closing any cell from which the truck has been removed.

Mounting.—The whole of the apparatus for each circuit equipment, including the oil circuit breaker, instruments and transformers is mounted on a movable truck. This truck can be withdrawn in the space allocated to the attendant, and then wheeled away for inspection. The open construction of the truck framework renders inspection of all the apparatus a very easy matter.

Contact Jaws.—The truck carries contact jaws mounted on porcelain insulators which engage with contact blades mounted in the fixed portion of the structure. These contact blades are sunk into the porcelain insulators so as to obviate danger of accidental shock or short circuits when the truck is removed. The same insulators also support the bus bars in the bus bar chamber and the cable terminals in the cable box chamber.

Interlocks.—Safety interlocks are fitted to all trucks, so that it is impossible for any truck to be withdrawn from the cell while the oil circuit breaker is closed; similarly the truck cannot be pushed into the cell unless the oil circuit breaker is open.

All parts are held together by means of bolt and lock nuts, so that any part can be readily removed and replaced in a sound mechanical manner.

The small wiring between the current transformers, trip coils, and instruments is permanently connected up and mounted on porcelain insulators attached to the frame of the truck.

The whole equipment is arranged so that ample clearances are allowed between the conductors, and from conductors to ground.

ELECTRICALLY OPERATED EQUIPMENTS

Arrangements.—Various standard arrangements for electrically controlled equipments are shown in Fig. 226. 'A' illustrates a typical vertical panel board with the instruments, control switches, relays, and similar devices mounted on the face of the panel. 'B' shows an arrangement of a control desk with the control switches placed on the desk and the instruments mounted on a wall in front of the operator. 'C' shows an arrangement of control desk where there are only a comparatively few meters, these being set flush in the face of the desk. 'D' shows a modification of the desk arrangement with the meters on a small slab or bracket extending up from the horizontal slab

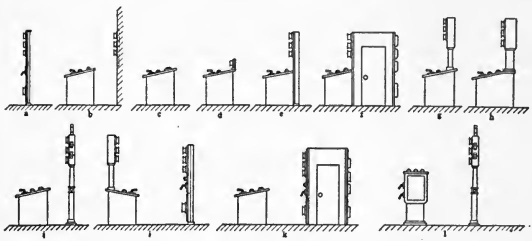


FIG. 226.—Arrangement of electrically operated boards.

of the desk. 'E' shows the control desk arrangement with vertical panels forming the back of the desk, the vertical panels containing the indicating meters. 'F' is a further modification of the control desk arrangement with vertical panels containing the indicating meters and a complete switchboard at the rear to contain the recording meters, relays, and similar devices. With this arrangement a self-supporting control desk is provided. 'G' shows the so-called gallery type of desk with the meters located on a framework supported above the horizontal slab of the desk at such a height that the operators standing at the control desk can look above the edge of the desk and below the meter panels to observe from the switchboard gallery the machine which he is controlling. 'H' is a modificaation of the gallery type of control desk. 'I' is a modified arrangement of control desk using a separate instrument frame supported on ornamental pillars, these pillars as a rule, being arranged to form the supports of a gallery railing. 'J' shows the combination of utilizing a gallery type control desk for the generators and vertical panel switchboard for the feeders. 'K' shows a combination control desk and panel board, the generator breakers being controlled from the desk, the generator instruments being on the vertical panels and all of the feeders being controlled from the vertical panels. The recording meters, graphic meters, and relays are placed on an auxiliary board back to back with the feeder board. 'L' shows an arrangement of control pedestals and instrument posts.

Pedestals.—In some of the earlier large capacity power plants equipments of control pedestals and instrument posts were utilized in place of vertical panels in conditions where present day practice would probably select the control desk as being the most suitable arrangement. Some of these earlier equipments of pedestals and posts have been superseded by more recent control desks but others are still in operation.

Where the number of generators was comparatively small in comparison with the number of feeder circuits, it was considered frequently of advantage to use control pedestals and instrument posts for the generator circuits and to take care of the feeder circuits by means of a panel switchboard. The instrument posts and control pedestals were self-contained, and additional posts and pedestals could readily be added with additional machines, without disturbing the symmetry of the arrangement.

Union E. L. & P. Co.—The original installation of pedestals and posts in the switching galleries of the Union Electric Light & Power Company of St. Louis is shown in Fig. 227, this equipment having been furnished for the control of eleven 6600-volt, 25-cycle, 3-phase generators of various capacities and a large number of feeders. The generator controlling devices were located on the pedestals, while the generator instruments were placed on posts, the posts acting as supports for the gallery railing. A station post containing voltmeters, synchronoscopes, etc., was so located that the instruments could be observed from any portion of the gallery. With the arrangement shown the operator on the switchboard gallery at the end of the station faced the generator room, while standing at the control pedestals and watching the generator instruments. The feeders were controlled from the panel board back of the operator, while the masonry structure for the bus bars and connections was back of the feeder board and located on the control gallery, as well as several lower galleries. Since the time of the original installation, the switchboard gallery was enclosed in glass, and the generator instruments were taken off the instrument posts, and placed on swinging panels attached to the framework of the glass enclosure. A later arrangement, due to remodeling of the plant makes use of a control desk equipment.

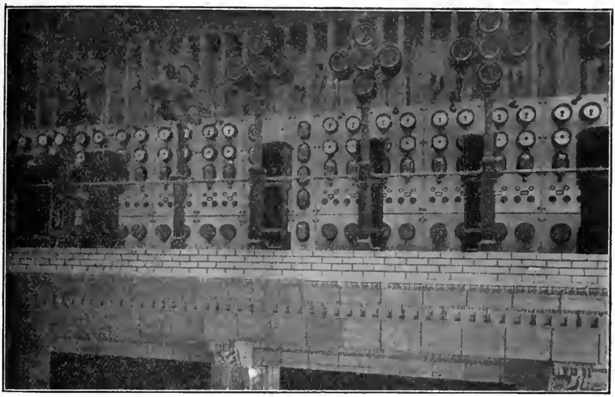


FIG. 227.—Pedestals and posts of Union Electric L. & P. Co. of St. Louis.

Generator Pedestals.—Each generator pedestal was provided with a controller for an electrically operated field discharge switch, a drum controller for a motor operated field rheostat, a drum controller for the engine governor, three oil circuit-breaker controllers with electro-mechanical tell tale devices and a 4-point voltmeter receptacle. At the top of the pedestal were placed synchronizing and signal lamps, while the synchronizing receptacles and plugs were located on each side of the lower circuit-breaker controllers. Each pedestal had a height of 4 feet 8¼ inches and occupied a floor space 14 inches square.

Generator Posts.—Each generator instrument post was equipped with a direct-current field ammeter, a 3-phase power factor indicator and three A.C. ammeters. These posts were provided with railing sockets and formed the supporting posts for the railing at the edge of the switchboard gallery. These instrument posts were made to contain various combinations of instruments, and had a standard height of 5 feet 7¼ inches to the bottom of the lowest meter, the total height to the top of grill work above the upper meter being about 8 feet 10 inches.

The Ontario Power Co. Control Room, at Niagara Falls, Ont., is shown in Fig. 228. At the time this photograph was taken the plant contained seven 8770-K.V.A. 12,000-volt, 3-phase generators, with banks of three 3000-K.V.A. transformers stepping up to 60,000 volts. The 60,000-volt feeder circuits running to Rochester, Syracuse, etc., were controlled from the panel board, while the two smaller pedestals placed near the telephone desk were used for the control of the exciter circuits. Various changes

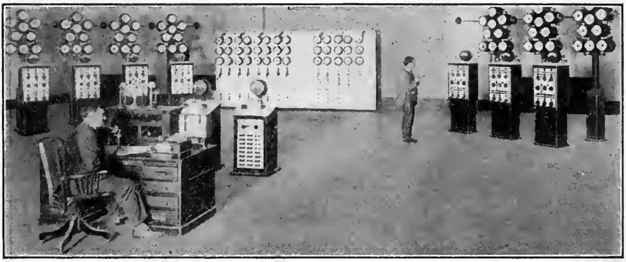


Fig. 228.—Control pedestals & posts of Ontario Power Co.

have been made due to modifications in the excitation system and plant at present comprises sixteen units and most of the energy is now delivered to the Hydro Electric Power Commission of Ontario.

Control Pedestals.—Each of the seven control pedestals was equipped with push-button control for the generator field rheostats and with a white signal lamp, that lit up when the field circuit was closed. The miniature bus placed on the face of the control pedestal shows two electrically operated oil circuit breakers in the main generator circuit, one placed in the power house at the foot of the cliff and the other being placed in the distributing station. The circuits from the generator after passing through these two breakers connected by the breaker controlled from the lower left-hand controller to one 12,000-volt bus in the distributing station, or passed through the breaker controlled by the middle controller to a common connection, where it branched and passed either through another breaker to a second

12,000-volt bus, or through a breaker on the low tension side of the step up transformers. The controller in the extreme upper right-hand corner took care of the breaker in the high tension side of the step up transformers. The two remaining controllers with circular handles were used, one for the control of the field rheostat and the other for the control of the speed governor motor. Suitable synchronizing lamps and receptacles were also placed on these pedestals. This type of pedestal is 5 feet 0 inches high and occupies a floor space approximately 24 inches by 14 inches.

Instrument Post.—Each post was provided with a single phase synchronoscope, a frequency meter, a 3-phase power factor indicator and transformer and generator ammeters and similar instruments. The base of the instrument post contained a number of calibrating jacks to permit the calibrating of the instruments without removing them from the posts. The total height of this post was 9 feet 0 inches and the width occupied by the meters was 2 feet 7⅜ inches.

Control Desk.—The control desk has many advantages where a very compact arrangement is desired to control the generators and feeders from the same switchboard, particularly where a group system of circuits is used and it is desirable to have a miniature bus bar to show the general scheme of connections and the arrangement of circuits in use. The desk has mounted on it the various controllers for the circuit breakers, field switches, field rheostats, etc. It is customary to mount the instruments in such a position relative to the sections of the desk, as to indicate clearly to the station operator the instruments belonging to any particular circuit.

With control desks the instruments can be mounted either on independent switchboards or panels forming the back of the control desk, or on an instrument frame back of and usually higher than the top of the control desk, or on instrument posts. In some cases the instrument can be set directly in the face of the desk.

Fig. 229 shows the front elevation drawing of the control desk supplied to the Williamsburg Generating Station of the Brooklyn Rapid Transit Company for the control of a number of 7500-K.V.A. and 10,000-K.V.A. turbogenerators, the desk as shown being intended for the control of nine machines.

Generator Equipment.—Each generator is provided with two electrically operated oil breakers in series with suitable disconnecting switches so that each generator can connect to its own feeder group bus or to the main bus. This main bus is sectioned by means of electrically operated oil breakers between generators 3 and 4, generators 5 and 6 and generators 7 and 8. Group breakers are also provided for connecting the feeder group busses to the main bus. Each feeder group bus supplied from

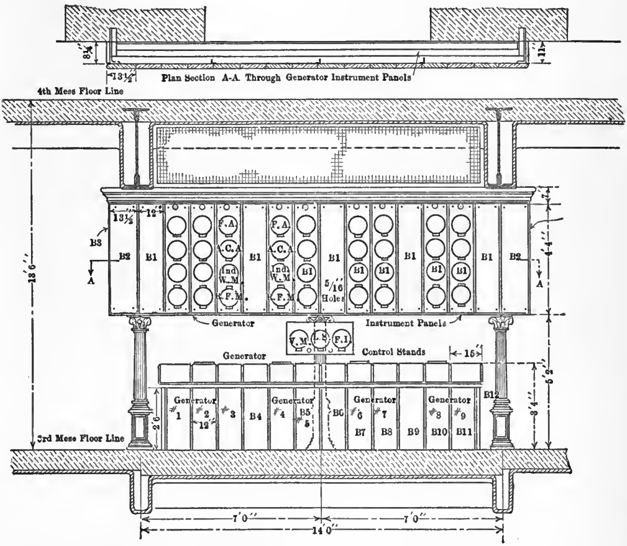


FIG. 229.—Front elevation desk, Brooklyn rapid transit.

three to six feeder breakers. The generator instruments are placed on a framework above the desk, so arranged that the station operator can readily watch the machines which he is controlling. Each generator section is provided with a field ammeter, an A.C. ammeter, a polyphase indicating wattmeter and a power factor meter, while a voltmeter was set in the top of the desk for one generator section in each group. A synchronoscope, frequency indicator and voltmeter were placed on a pivoted slab attached to the center-post of the instrument frame back of the desk.

A sectional view is shown in Fig. 230 of this same control desk which indicates the relative location of the desk and instrument board, as well as the location of the apparatus on the face of the control desk with the relays and similar devices on the back of the desk.

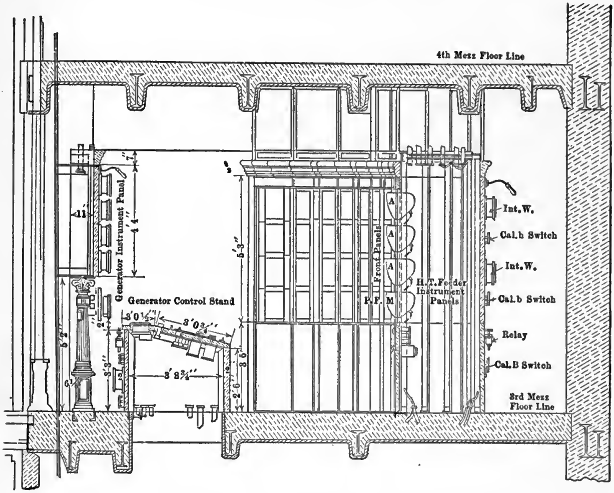


Fig. 230.—Side elevation desk, Brooklyn rapid transit.

Feeder Board.—The feeders in this installation are controlled from a vertical steel switchboard arranged in the form of an arc of a circle back of the control desk, so that the station operator turning around from the generator desk can readily observe any of the feeder circuits. This feeder switchboard is made of two concentric boards placed back to back, the board on the concave side next to the generator desk containing the feeder indicating instruments of the vertical edgewise type, and the controllers and indicating lamps used with the electrically operated breakers of the feeder circuits, while the switchboard on the convex side contains the polyphase watt-hour meters, the overload relays and the calibrating switches supplied for the various feeder circuits.

Desk with Horizontal Edgewise Meters.—Fig. 231 shows a control desk with horizontal edgewise meters placed on slate slabs above the desk, while the various control switches with their indicating lamps are mounted on the slate apron of the desk and the time limit relays are located on the front panels of the desk. With the arrangement shown the station operator faces the generator room when standing at the desk and looks over the desk and under the frame to watch the machines.

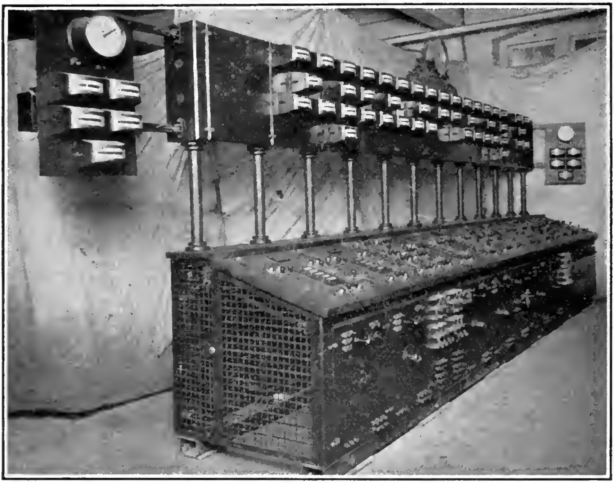


FIG. 231.—Control desk, General Electric Co.

Desk with Vertical Edgewise Meters.—A control desk with vertical edgewise meters supplied to the Pratt Street Power House of the United Railway & Electric Company of Baltimore is shown in Fig. 232, controlling a number of 13200-volt, 25-cycle, 3-phase, generators and outgoing feeder circuits. This desk was arranged to form an arc of a circle and was ultimately to be about twice as large as the portion shown. A complete miniature bus bar system located on the top of the desk shows the connections made by the various breakers that were arranged on a group and ring system. In this plant each generator was provided with a circuit breaker connecting the generator to its own bus bar. This bus bar connected in turn through a main breaker to the main bus or through either of the two group breakers to two group busses, each group bus supplying the current to four feeder circuits. By closing the various group breakers, the group busses form one complete ring bus and the main bus forms the second ring bus, so that a very flexible arrangement was secured.

Calibrating jacks were installed on the front panels of the control desks to permit any of the switchboard instruments to be

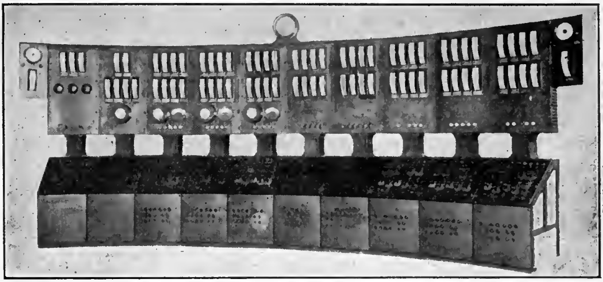


Fig. 232.—Control desk with vertical edgewise meters.

calibrated in position. The vertical edgewise instruments were mounted on steel plates forming the instrument frame, while the relays were located on the rear of the desk.

Desk with Round Pattern Meters.—Fig. 233 shows a control desk of the gallery type furnished by the Westinghouse Electric & Manufacturing Company to the Inawashiro Hydro Electric Company of Japan for the control of four exciters, six 7700-K.V.A. generators, four banks of transformers, various feeder circuits. The desk comprises a pipe framework having mounted on it nine sections of marine finished slate containing the various controllers, indicating lamps and similar devices while a separate instrument frame is furnished supported by pillars from the control desk and containing the various meters needed for the installation.

All of the controllers and indicating lamps for the D.C. system of exciters and field circuits are placed on the front of the desk while the controllers and similar devices for the A.C. circuits are located on the horizontal top of the desk.

A complete miniature bus bar system is placed on the desk to show the connections made by the various breakers, red indicating lamps being connected into the miniature bus bar system

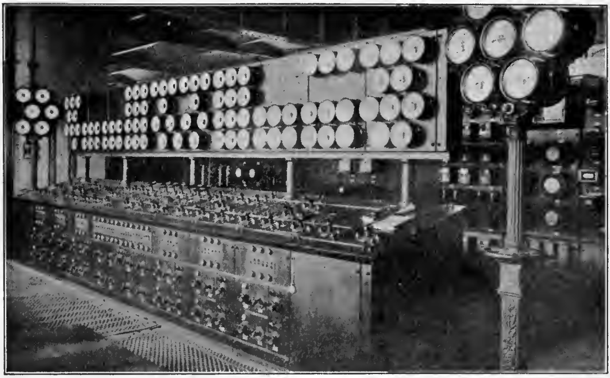


FIG. 233.—Control desk with round pattern meters for Inawashiro.

in such a manner that they light up when their particular breaker is closed. The miniature high tension bus on the horizontal slab of the desk is nickel plated and the corresponding low tension bus is polished copper. The field and excitation bus is distinguished by its location on the front part of the desk.

CHAPTER XV

BUS BARS & WIRING—GENERAL INFORMATION

Having considered the apparatus and the panels that are used for the switching equipment, the next important matter to be taken up is that of the bus bars and wiring; after which the arrangements of breaker and bus structures and the general layout of the portion of the power plant devoted to the switching apparatus will be discussed.

Bus Bars.—In order to provide facilities for utilizing the current developed in an electrical generating station to the best advantage, it is customary to have one or more sets of circuits into which the various generators deliver their current and from which the various feeders draw their current. These common circuits are known as "omnibus bars" or "bus bars."

In the simplest station with only one generator and only one feeder the generator connects directly to the feeder but in practically every other case, with more than one feeder or more than one generator, bus bars are required.

D.C. Busses.—With shunt-wound D.C. machines it is necessary to have a positive bus and a negative bus; while if two shunt machines are run in series, on a 3-wire system, a neutral bus is also needed. With compound wound generators an equalizer bus is required, and when two compound wound machines are run in series on a 3-wire system or when a compound wound 3-wire D.C. generator is used, five busses are needed—positive, positive equalizer, neutral, negative equalizer and negative. For 2-wire service the feeder circuits only connect to the positive and negative bus bars while for 3-wire service they also connect to the neutral, but the equalizer busses only connect to the generators. For railway circuits with ground return the feeders only connect to one bus, usually the positive, the other main bus (the negative) being grounded and the equalzer bus merely running between machines.

A.C. Busses.—In single phase A.C. systems there are two busses, in 2-phase systems usually four busses, and in 3-phase usually three busses. The single-phase system may be 3-wire, the 2-phase may be 3-wire or 5-wire, while the 3-phase may be 4-wire with the corresponding number of bus bars.

Where there is only a single set of bus bars either in D.C. or A.C. stations the connections are said to be arranged on the "single throw" system; when the connections can be made to either of two sets of bus bars the system is spoken of as "double throw", while if the connections can be made to both sets of bus bars instead of only to either set the system is spoken of as the "selector system." Occasionally three or more sets of bus bars are used.

If there is only one set of bus bars but switches are provided for dividing it into one or more sections it is spoken of as a sectioned bus. Where there are two sets of these sectioned bus bars connected together at the ends, the system forms a ring bus. In many high voltage plants having step up transformers each generator normally connects to the low tension side of its own transformer but switches are provided so that any transformer or generator can connect to a bus, such a bus is spoken of as a relay bus. Where a number of feeders connect to a bus which in turn connects to the main bus through a switch or breaker such a bus is spoken of as a group bus. These various arrangements are shown on the diagrams in a previous chapter.

Systems.—The various systems—single bus, double bus, relay bus, group bus, etc., all have their advantages and disadvantages. The single bus is naturally the cheapest, simplest and least flexible and trouble on the bus is apt to shut down the plant. The other systems are more flexible, and also more expensive as they require more apparatus. In every installation a compromise must be effected between cost and flexibility, and each case must be considered on its own merits. In small low voltage plants bus bar trouble is almost unknown and a single-throw system is usually employed. In high voltage large capacity plants although bus bar trouble is rare, a more flexible system than the single throw is often advisable.

Material.—Depending on the current and voltage, bus bars may be made of wire, rod, tubing, cable or strap, either bare or insulated. Solid wire is seldom used for more than 200 amperes, rod for 1000 amperes, tubing 300–600, cable 1000, while strap is used up to any capacity. Strap for bus bars possesses several advantages over other shapes, the chief ones being the ease with which additional straps may be installed and the excellent radiating surface secured.

Straps of different sections are in use, a typical one being 3 inches by 1/8-inch. Where more than one strap is required, a space is kept between adjacent bars making the so-called laminated bus. The usual spacing left with 3 inches by 1/8-inch bars is 3/8-inch. The connections from switches, circuit breakers, etc., to the bus are made of one or more similar straps suitably interleaved and clamped together.

Current Capacity.—Due to the large surface exposed in comparison to the section of copper used, comparatively high current density may be employed for a small number of straps without exceeding a safe temperature rise. The exact amount of current to be carried for a given rise depends somewhat on local conditions, ventilation, etc., and whether the bus is being used for direct-current, 25-cycle, or 60-cycle service, and the temperature rise is not the same for different parts of the bar. A typical test under average conditions, 60-cycle service, 25-degree rise, indicated that one bar would carry 650 amperes, two bars 1150 amperes, three 1500, four 1800, five 2000, six 2160, showing that due to "skin effect," lack of ventilation, etc., the permissible current density falls off rather rapidly as the number of bars increases. It is usually necessary to interleave the phases for 60-cycle service to carry 3000 amperes or more without an excessive amount of copper.

Bus Compartments.—In large capacity A.C. plants of 13,200 volts or less, with generators connected directly to the bus, the amount of current that can be concentrated on a short circuit is something enormous and every precaution has to be taken to prevent trouble from spreading if it ever starts. For this reason it has become customary to employ masonry compartments and cellular construction for the oil circuit breakers and bus bars.

As the main idea of the cellular scheme is to provide an insulating fireproof barrier between leads of opposite potential in heavy capacity plants of 13,200 volts or less the material to be used for the structures, barriers, etc., is of the utmost importance. The vertical walls and septums of the circuit-breaker and bus bar structures are usually built of brick or concrete while the horizontal shelves between the bus bars are ordinarily made of concrete, soapstone, slate or marble. In some instances the bus bar structures have been made of asbestos lumber, transite or similar material.

Brick Work.—The brick used for structural work of this kind is usually a good class of pressed brick, fire brick or enameled brick put up with cement mortar and presenting a fine appearance. In order to keep down the cost, it is sometimes arranged to use the finer grades of brick for such portions of the structure as are visible from the operating room or noticeable to the average visitor while a cheaper grade is used for such other parts as are normally not seen. The advantages of brick for this class of work are that it has ample strength to support the weight and to stand the jar of opening of a heavy breaker, and it is easy to secure good bricklayers in almost any locality. Its disadvantages are chiefly due to its relatively fixed dimensions, the difficulty of reinforcing thin walls of any considerable height and the trouble experienced in locating conduits for control leads, etc., as well as the fact that it is practically impossible to make the horizontal shelves of the same material as the vertical walls when brick is used.

Concrete.—This possesses most of the advantages of brick without the disadvantages of relatively fixed dimensions and as it can be easily reinforced and can be made into horizontal shelves for bus bar work it is rapidly becoming a favorite material for such structures. When concrete is used it is a simple matter to imbed the conduit for the control leads, the tie rods for the breakers, the bolts for switch bases, transformers, etc. in the structure. Concrete, however, is somewhat more apt to absorb moisture than brickwork but when dry is a comparatively good insulator and resists the destructive effects of an arc as well as anything used for the purpose.

Shelves.—Horizontal shelves between bus bars have been made of marble, slate, soapstone, sandstone, concrete or similar material and historically they have been used about in the order named which is also the order of their decreasing cost. Marble is undoubtedly the best material as far as insulation and absorption qualities go, but its high cost and its crumbling when exposed to a bad arc has caused the adoption of cheaper materials of slightly poorer insulating qualities. Slate, the next material tried, is a very uncertain insulator for high voltage work and it has been generally superseded by soapstone, sandstone or concrete. Where space is at a premium, soapstone is used almost exclusively as it can be drilled, machined, etc., and smaller clearance distances can be used than would be permissible with sandstone or concrete. Where there is a chance to secure a reasonable distance between bare metal parts and the shelves or barriers, concrete, either plain or reinforced, can be used to advantage.

Between disconnecting switches and in such places where the barrier wall does not carry any additional weight, asbestos board, wire glass, etc. has sometimes been used.

Enclosures.—Masonry structures for bus bar work are made either semi-enclosed or entirely enclosed. In the former case the wall of the structure which separates the horizontal bus bars and the vertical connections is made practically continuous. The back of the bus bar shelves are built into this wall while pilasters properly spaced support them in the front. Except for these pilasters the bus bar structure is open in the front and the septums in the rear that separate the leads are usually left open. This scheme leaves the bus bars and connections readily accessible and well ventilated but makes it possible for a careless visitor or attendant to come in contact with the bus or connection.

A modification of this scheme uses a continuous wall instead of pilasters as a support for the front of the shelves and the bus bars, connections, etc., are almost completely enclosed except for openings provided with doors at the supports, contacts, etc. With this arrangement it is impossible for any one to touch any live metal parts without removing a door, but the busses, connections, etc., are not so accessible or so well ventilated as with the more open arrangement.

Leads.—Where the leads pass through the floor or the back wall of a bus bar structure, either of two schemes may be adopted. With the first, porcelain bushings are used to give the necessary insulation while with the other scheme holes of generous dimensions are made and the lead run through the middle of this hole. In one case porcelain insulation is used and in the other air. The former makes a tighter joint with less likelihood of smoke or flame passing from one compartment to the next but is more expensive and more subject to insulation trouble than the latter.

Connections.—For bus bars and connections where the currents exceed 600 or 800 amperes it is usual to employ laminated copper straps while for smaller currents cable, wire, rod, or tubing is used. Cable, and to a certain extent wire, is used for connections involving bends or long runs through conduit, while for straight runs or simple bends rod or tubing can be used. Tubing while more costly than rod or wire for the same section is stiffer and can often be flattened out for making connections to studs, bars, etc. without the necessity of additional terminals.

Laminated Bus.—One of the advantages of the laminated copper strap is the large amount of radiating surface secured with the minimum amount of material, and the readiness with which it is possible to taper the bus bars so as to utilize the material to the best advantage adjusting the capacity of the bus to the total amount that will have to be carried at any one point.

Another great advantage is the facility with which additional strap may be added if it is desired to increase the capacity of the bus at any time. Another advantage is the ready means by which connections can be made if laminated copper straps are used which will interleave with the bus, and which connect the bus to the studs of disconnecting switches, circuit breakers or similar appliances.

Supports.—As supports for the low tension bus bar, insulators of various kinds have been designed, these usually being made of porcelain either in the shape of cylindrical or conical pillars, or in the form of petticoat insulators depending on the voltage of the circuit.

Low tension bus bars, when not too heavy, can be supported by the wall bushing for the lead. For heavier work, or where bushings are not used, the bus bars are supported on porcelain pillars, petticoat insulators, and similar devices resting on the bus bar shelf, or attached to the wall.

Bus Stresses.—In the larger generating stations, due to the tremendous values of short-circuit current resulting from the size and number of turbogenerators represented in present day station practice, close attention must be given to the adequacy of the bus bar supports. Various curves and formulæ have been deduced for the purpose of calculating the mechanical strain on bus bar supports at the instant of short circuit. A typical formula is the following:

$F = .27 \times \text{K.V.A.}^2$ divided by $A \times V^2 \times Z^2$ where

F = maximum force exerted in pounds per foot of bus.

K.V.A. = normal rating of the station including all synchronous apparatus.

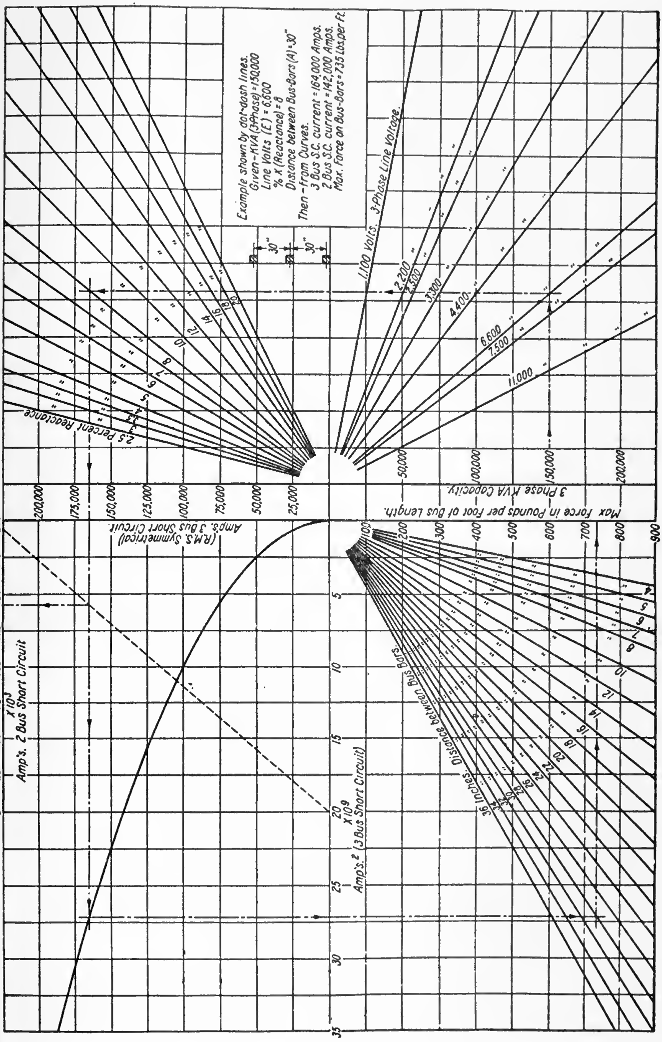


FIG. 234.—Diagram of bus bar stresses.

A = distance between busses in inches.
Z = impedance in per cent. expressed in decimals to the point of short circuit.
V = line voltage.

Fig. 234 and 235 are graphic representations of this formula. In using this formula a typical example with 150,000 K.V.A. station capacity at 6600 volts, 8 per cent. reactance gives a maximum force on the bus bars per foot of length, 735 lbs. with 30-inch spacing between bars, 1470 lbs. with 15-inch spacings between bars. With four feet between bus supports each bus support would have to stand a strain of 2940 lbs. if the busses are 30 inches on centers, 5880 lbs. if the busses are 15 inches on centers. For heavy duty of this kind, multi-point supports are frequently used.

For supports of high tension bus bars and connections it is customary to employ high tension insulators of the pillar type, pin type, or suspension type, depending on the voltage.

Extra High Tension.—Where the generators connect through separate transformers giving voltages from 22,000 to 154,000 or even higher, the question of enclosing the bus bars and wiring for the high tension circuits becomes an entirely different proposition.

Some engineers were originally of the opinion that the cellular construction should be used for large capacity circuits of any voltage, and bottom connected breakers have been designed that work in well with the enclosed bus bar construction for high voltage plants.

Open Construction.—The almost universal American opinion at present is that the open system of wiring is preferable for any voltage higher than that for which generators can be conveniently wound. It is based on the following reasons:

First.—The violence of an arc and the destructive effect of short circuits depends on the amount of current available at that point. While fireproof barriers and cellular construction are required on large capacity plants of comparatively low voltage, they are unnecessary for higher voltage plants of the same or even larger capacity.

Second.—The distance from wire to ground has to be greatly reduced over what could be obtained with open wiring in the same space as the fireproof barriers offer a more or less perfect

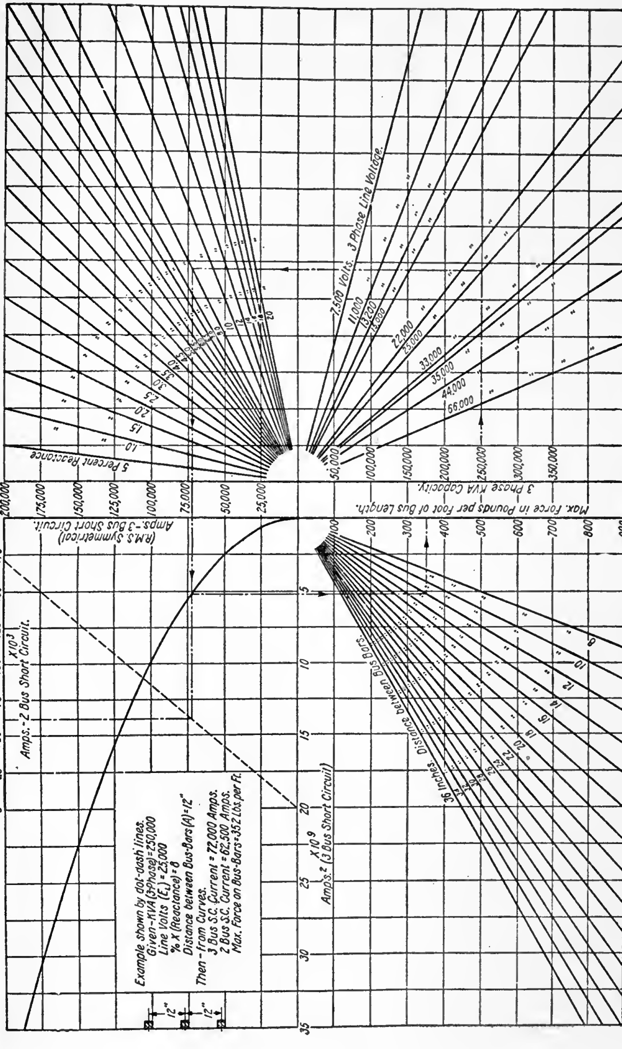


FIG. 235.—Diagram of bus bar stresses.

ground for high voltage circuits and the higher the voltage the more perfect the ground.

Third.—A more expensive building and costly construction are usually needed for enclosed bus bars and wiring than are required for open wiring.

Fourth.—Inspection and repairs are more difficult for bus bars, wiring, disconnecting switches and similar appliances that are boxed in masonry compartments, and are only visible and accessible by the removal of doors, than if everything is in plain sight. Inspection will be more frequent and thorough and incipient trouble will be noticed far sooner with open wiring than with enclosed, as the station attendant in a few minutes walk can see everything and will not have to remove many doors and visit two or three floors to examine the condition of the apparatus.

In most cases the desirable features of the open system of wiring for high voltage can best be secured by the use of outdoor transformers and switch gear.

Tubing.—For extremely high voltages with the corresponding small current, copper tubing for bus bars and connections has many advantages over rods, wire or strap, these advantages being principally increased stiffness for the same amount of material, large and effective radiating surface and the facility of making connections by flattening out the tubing at the point desired and bolting the tubing together at such points. Tubing of approximately 1 inch outside diameter is not apt to be troubled by the brush discharge or corona effect that is sometimes noted with small wires or strap having sharp edges when used on extremely high voltage circuits. In many cases standard iron tubing is employed.

Supports.—For supports for such high tension bus bars and connections it is customary to employ line insulators either of the pillar type, pin type, or suspension type, depending on the voltage.

Connections.—For the connections between generators, transformers, feeder circuits and their switching gear, it is occasionally possible to use bare copper conductors, although in most cases particularly for the connections between the generators, the low tension side of step up transformers and their switch gear, insulated wire or cables are better adapted for the actual arrangement of the station.

Cables.—On all circuits of more than 200 amperes the leads usually consist of cables, the number and size depending on the current to be carried and other considerations. It is often practicable to use the same size of cable, *e.g.*, 500,000 C.M. for all the main connections in one plant, using as many cables in multiple as may be required, and in this manner utilizing the cable to better advantage than if each circuit had different sizes of leads. Proper terminals can always be supplied on the switchboard or machine to suit any reasonable cable requirements. The sizes of cable used should usually correspond with the carrying capacities as given by the National Board of Fire Underwriters unless there are considerations of excessive line drop in a long feeder or some other reason for departing from their regulations.

Underwriters.—As far as possible all wiring, etc., on switchboards strictly corresponds with the requirements of the National Board of Fire Underwriters, but it has been found impracticable to attempt to wire up the back of switchboards used on voltages above 600 with fireproof wire owing to the poor insulating qualities of the fireproof covering and the consequent necessity of stripping back this braid for several inches from all terminals, etc., on the back of the board.

CONTROL AND INSTRUMENT CABLE

Multiple Cable.—For the connections between series and shunt transformers, their instruments and relays, and between the controlling devices, and the circuit breakers, switches, etc., that are controlled, it is customary in American practice to supply multiple conductor cables, each conductor being provided with distinctive braid to facilitate the more ready checking of the wiring after it is installed. This multiple conductor cable is usually made either with a fireproof braid or with a lead cover, and is frequently run in iron pipe conduit.

As the instruments and control switches for electrically operated switchboards are usually located some distance from the meter transformers, circuit breakers, rheostats and other accessories, it is necessary to use connecting leads of varying lengths. For this purpose, multiple conductor cables are used.

Size of Cable Required.—The sizes of conductors generally used, where lengths do not exceed 500 feet, are as follows:

For current transformer circuits, each lead should be equivalent to 19,500 circular mils and for very short runs 10,000 circular mils. For potential transformer circuits, each lead should be equivalent to 10,000 or 6,000 circular mils.

For small solenoid operated circuit breakers, closing coil leads should be equivalent to 19,500 circular mils; tripping coil and indicator leads equivalent to 6000 circular mils; return circuit being same size as closing-coil lead, either in same cable or separate.

For large oil circuit breakers on control circuits of 125 volts or lower, it is sometimes considered advisable to use a heavier closing lead. In every case it is advisable to carefully check the drop in the closing circuit to insure proper operation of the breaker, as in some cases very heavy leads will be required. When a relay switch is used, the lead from the control switch is

Rubber-insulated, Braid-covered, Weatherproof and Flameproof Multiple-conductor Cables for Auxiliary Circuits

Number of conductors	Stranding of each conductor, inch	Circular mils	Diameter, inches		Approx. wt., lbs. per 1000 ft.
			Bare copper	Over outer braid, maximum	
2	19 of 0.0179	6,000	0.0895	0.57	150
2	19 of 0.0226	10,000	0.113	0.62	195
2	19 of 0.032	19,500	0.160	0.78	325
3	19 of 0.0179	6,000	0.0895	0.61	190
3	19 of 0.0226	10,000	0.113	0.66	225
3	19 of 0.032	19,500	0.160	0.84	430
3	One 19 of 0.032	19,500	0.160	0.70	230
	Two 19 of 0.0179	6,000	0.0895		
3	One 37 of 0.0359	47,500	0.251	0.81	415
	Two 19 of 0.0179	6,000	0.0895		
4	19 of 0.0179	6,000	0.0895	0.66	210
4	19 of 0.0226	10,000	0.113	0.72	300
4	19 of 0.032	19,500	0.160	0.92	540
4	One 19 of 0.032	19,500	0.160	0.76	375
	Three 19 of 0.0179	6,000	0.0895		
4	Two 19 of 0.032	19,500	0.160	0.76	375
	Two 19 of 0.0179	6,000	0.0895		
5	19 of 0.0179	6,000	0.0895	0.75	260
5	19 of 0.0226	10,000	0.113	0.82	350
5	Two 19 of 0.032	19,500	0.160	0.86	450
	Three 19 of 0.0179	6,000	0.0895		
6	19 of 0.0179	6,000	0.0895	0.80	385
6	19 of 0.0226	10,000	0.113	0.88	500
6	19 of 0.032	19,500	0.160	1.12	760
7	19 of 0.0179	6,000	0.0895	0.80	420
7	19 of 0.0226	10,000	0.113	0.88	540

only large enough for the operating current in the relay switch, for which purpose 6,000 circular mil cable is usually adequate.

For engine governor control or electrically operated rheostat control, each lead should be equivalent to 10,000 or 6,000 circular mils; three, four or six leads being used, as required. The cables listed below are particularly adapted to the diverse requirements of switchboard service.

Insulation.—Each individual conductor is insulated for 600-volt service and is covered with braid with an identifying color. The insulated conductors are assembled and covered with a layer of tape and an outer braided covering or lead sheath. The outer covering of the cable selected depends upon the nature of the installation.

RUBBER-INSULATED, LEAD-COVERED, SINGLE AND MULTIPLE-CONDUCTOR CABLES FOR AUXILIARY CIRCUITS

Number of conductors	Stranding of each conductor, inch	Circular mils	Diameter, inches		Approx. wt., lbs. per 1000 ft.
			Bare copper	Over outer Braid maximum	
1	19 of 0.0226	10,000	0.113	0.37	390
1	19 of 0.032	19,500	0.160	0.45	530
1	37 of 0.0285	30,000	0.200	0.49	600
1	37 of 0.0359	47,500	0.251	0.55	720
2	19 of 0.0179	6,000	0.0895	0.65	600
2	19 of 0.0226	10,000	0.113	0.69	735
2	19 of 0.032	19,500	0.160	0.88	930
3	19 of 0.0179	6,000	0.0895	0.68	715
3	19 of 0.0226	10,000	0.113	0.73	805
3	19 of 0.032	19,500	0.160	0.94	1,180
4	19 of 0.0179	6,000	0.0895	0.73	800
4	19 of 0.0226	10,000	0.113	0.79	915
4	19 of 0.032	19,500	0.160	1.02	1,400
4	One 19 of 0.032	19,500	0.160	0.86	1,025
	Three 19 of 0.0179	6,000	0.0895		
4	Two 19 of 0.032	19,500	0.160	0.94	1,200
	Two 19 of 0.0179	6,000	0.0895		
5	19 of 0.0179	6,000	0.0895	0.82	1,200
5	19 of 0.0226	10,000	0.113	0.92	1,300
5	Two 19 of 0.032	19,500	0.160	0.90	1,400
	Three 19 of 0.0179	6,000	0.0895	0.90	
6	19 of 0.0179	6,000	0.0895	0.90	1,040
6	19 of 0.0226	10,000	0.113	1.10	1,200
6	19 of 0.032	19,500	0.160	1.25	1,700
7	19 of 0.0179	6,000	0.0895	0.90	1,075
7	19 of 0.0226	10,000	0.113	1.10	1,200

Colors of Leads.—The colors used by one manufacturer in identifying the individual conductors are as follows: First, black; second, white; third, red; fourth, green; fifth, yellow; sixth, blue; seventh, yellow and green. For example, a four conductor cable requires the use of the first four colors, black, white, red and green.

When conductors of different sizes are used in a multiple conductor cable, the sequence of colors given above is followed in the order of the capacities, the largest conductors having a black braid, the next largest a white braid, etc.

BUS SUPPORTS

Early Types.—In the earlier station designs the use of petticoat insulators mounted on pins for supporting high tension bus bars and wiring was practically imperative, owing to the lack of supports specially designed to meet the conditions. This practice was quite general and in some instances is still standard, especially when extensions to old work are necessary. The use of petticoat or line insulators had the advantage of employing a standard part usually available or easily secured.

Progress.—There were, however, many objections to their use, especially when compactness, flexibility and neat appearance of bus bar work were important. The petticoat type of insulator support is not well adapted for horizontal mounting, and for installations where a back connected type is necessary the petticoat form cannot be used to advantage. It is not easily inspected or cleaned and in bus bar compartments the danger of dust or dirt accumulation on the inner petticoat surface is apparent. Owing to manufacturing difficulties, it is practically impossible to secure uniform dimensions of petticoat insulator grooves, heights, etc., and as a result the general "line up" of the conductor or bus is apt to be irregular. The large space required is also frequently objectionable, especially when bus bar or wiring compartments are used.

Pillars.—As station design progressed the bus bar or high tension wiring supports began to receive closer attention, first by European and then by American engineers. The earlier European designs comprised a corrugated pillar having recesses at both ends into which were rigidly cemented the desired fitting to clamp a bus bar, mount on pipe frame work or flat support.

Cementing.—The practical objection to this early foreign standard was that the rigidly cemented fittings and insulators resulted in an inflexible unit, difficult to install. In case of changes in the number or size of busses, necessity of substituting pipe work for flat base pins, etc., the limitations became very apparent, as it was necessary to remove the entire unit, substituting a second complete unit in its place. In short, the construction employed in the early European designs was electrically good but mechanically inconvenient, expensive and cumbersome. It was a rigid, inflexible design not well adapted to American practice.

Another serious objection to the original type was that it was impossible for manufacturers or users to carry a complete stock, as the fittings of each particular size were rigidly cemented in place and parts could not be interchanged. Factory shipments were, therefore, slow and the user always had an equipment devoid of interchangeable features.

Post Type.—The next step in design and manufacture of bus bar supports was the "post type," consisting of a corrugated post provided with removable top and bottom clamp fittings. This improved design eliminated the interchangeability limitations of the older pillar type, having rigidily cemented fittings, so the parts could be adjusted or replaced as desired. The disadvantage of the "post type" support was that the method adopted of attaching the top and bottom clamps on the outside of the insulator materially cut down the leakage surface. As the clamps extended over at least one corrugation, this design also necessitated greater dimensions in order to maintain the same factor of safety secured with the older form of cemented "pillar type supports."

Clamps.—The clamps at top and bottom were also considerably wider than employed with the older "pillar supports," necessitating wider spacings between insulators, greater clearances for height, use of larger bus bar compartments and as a final result a larger substation or station building.

These clamped supports are made by various builders with different features. Those of the Westinghouse Company have been selected as illustrating the general type.

Westinghouse Supports.—Type P bus supports of the Westinghouse Electric & Manufacturing Company, with corrugated insulators consist essentially of an insulator with suitable bus and mounting fixtures clamped on.

The insulators are made of porcelain by wet process and have a brown mahogany glaze. The insulators are corrugated to insure ample creepage surface under service conditions. The fittings are made of malleable iron or cast brass and have a high-grade dull black, baked finish. Interchangeability of fittings on porcelains of different voltage but of same diameter of head or base is provided.

Stresses.—Mechanical stresses due to short circuits on the bus bars must be considered in selecting the type and size of

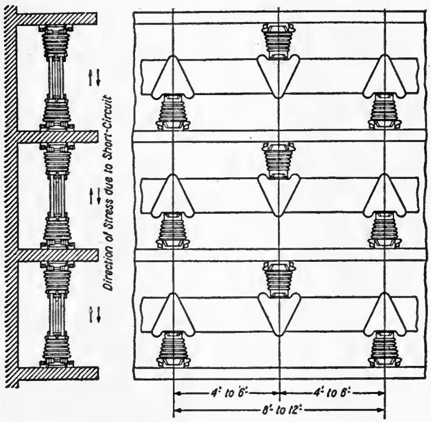


FIG. 236.—Bus bar supports with braces.

support. These short-circuit stresses may depend on the maximum ampere load, under short-circuit conditions, the distance between center line of bus bars and the relative location of the bus bars.

To meet these varied requirements, several sizes of insulators are made for the lower voltages, from which proper selection may be made.

Heavy Supports.—Insulator supports for extra heavy busses can be supplied, when desired, with insulator braces between the bus bars, as shown in Fig. 236. The complete support and brace are made up of standard parts. This arrangement is equally adaptable for frame or cell mounting.

Tests.—Voltage tests with all fittings on are given in table below. These tests are ample for ordinary applications and are well within the requirements of the recommendations of the American Institute of Electrical Engineers. The large creepage surface provided by the corrugations insures the ability of the insulator to stand the same test under service conditions.

Maximum service voltage	One Minute dry test volts
7,500	20,000
15,000	40,000
25,000	65,000
35,000	90,000
44,000	115,000

For exceptional installations where an insulator of a high voltage test may be desired, next higher maximum service class may be used.

Fig. 237 shows an extra heavy duty bus arrangement, busses vertically mounted in same horizontal plane with barriers.

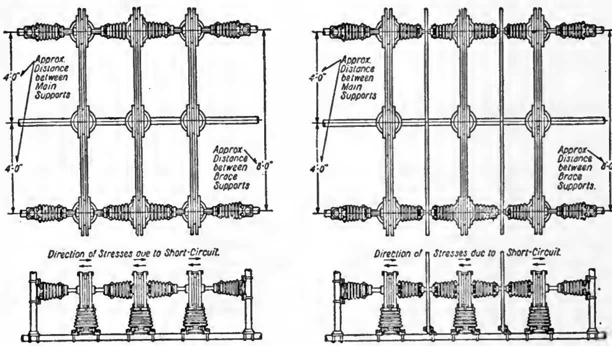


Fig. 237.—Heavy duty bus support.

This arrangement employs standard supports requiring the same number as is ordinarily used for single supports, but so disposed that one half of the porcelains are in compression from short-circuit stresses.

Compression.—The rating of the supports can be increased to meet the demands of extra heavy duty, by so locating the supports, that some of them will always be in compression under short-circuit stresses.

A series of typical insulators with the various clamping devices and switchboard details is shown in Fig. 238, while the applica-

Fig. 238.—Bus fittings & details.

tion of these devices and various standardized details as furnished by the Westinghouse Company are shown in Fig. 239.

Delta-Star.—Other makers of fittings have adopted different methods of attaching the metal parts to the porcelain insulators and claim certain advantages for their designs. The Delta-

Star Company have a line of "Unit Type Bus Bar Supports" that they have developed and which they consider superior to the clamped type for different reasons, given below.

Objections to Post Type.—Owing to their greater weight and size, larger and heavier and more expensive supporting structures were necessary than with the pillar form. For moderate potentials, 22,000 volts and less, the "post type" insulators were abnormally large and heavy, did not permit of a neat construction and were altogether out of proportion for the work

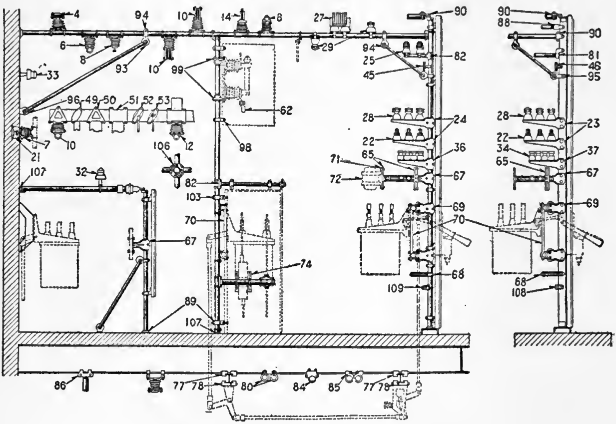


Fig. 239.—Westinghouse switchboard details.

to be accomplished. While the "post type" insulator was an improvement from a manufacturing standpoint, it did not work out so advantageously for the user, especially when making extensions. Owing to the increased size and weight (necessitating greater clearances, etc.) it was frequently an impossibility to install the "post type" in existing substations or wiring systems where a given place had been provided for future extensions.

Unit Type.—The problem presented by modern conditions was then given close attention and after consulting experienced power house engineers the final standard adopted was the "Unit Construction" bus bar supports. These supports have all the advantages of previous types with none of the disadvantages and permit of a flexibility in manufacture, assembly and installation impossible to obtain in the older forms.

The "Unit Type" wet process corrugated porcelain pillars are recessed at each end and provided with a sanded surface socket in which is cemented a malleable iron thimble, threaded to receive the proper fittings for the service to be met. The advantages of this construction will be quickly appreciated by engineers, as a flat base mounting can quickly be converted to a pipe frame mounting, etc.

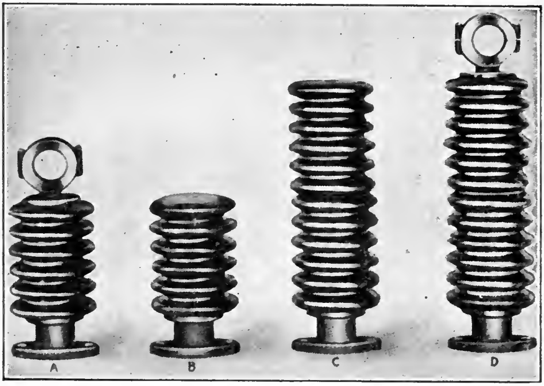


FIG. 240.—Unit construction, bus bar supports.

Changes.—If future requirements make it desirable to change bus bar sizes it is simply necessary to remove the original fitting and install a new one of different type or size.

The wet process insulators are finished in dark brown glaze, the metal parts having black enamel finish. This combination of colors insures a pleasing, permanent finish corresponding to other high-grade switchboard and bus structure equipment.

The "Unit Construction" has an additional advantage in that bus bar supports can easily and quickly be reconstructed for higher potentials by the user. A good example of this desirable feature is shown in Fig. 240. The support to be increased in voltage rating is shown at 'A,' the insulator unit with bus bar clamp removed at 'B,' the additional unit is in position at 'C' and the complete assembly is shown at 'D.' This flexibility of design will be fully appreciated if it becomes necessary to make changes in the bus bar construction.

Bases.—The seven styles of bases shown in Fig. 241 will be found to meet practically every condition encountered in the installation of busses and general station wiring. Special bases to meet local conditions can be supplied.

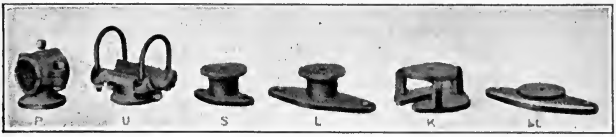


Fig. 241.—Bus bar base fittings.

Clamps.—Bus bar clamps for "Unit Type" supports are shown in Fig. 242, Type 'I' clamp. The type 'I' clamp is of the two bolt form designed to support flat copper bars in a horizontal position on horizontal structures or in a vertical position from vertical structures. The former method is generally used in enclosed bus bar compartments where it is essential to limit the height of the compartment. The latter method is

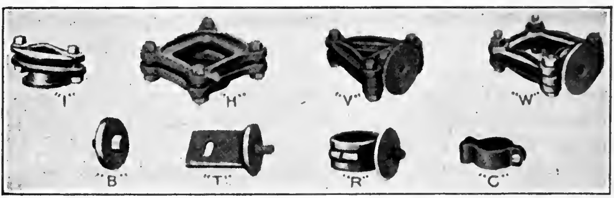


Fig. 242.—Bus bar clamps for unit type supports.

more applicable to open bus bar work. Other clamps for different purposes are available with various numbers of bolts.

Bus Switch.—The "Unit Type" bus switch shown in Fig. 14 of Chapter 1 is an interesting application of the "Unit Type" insulators. This switch is designed to clamp directly on the bus bar, and is a convenient method of inserting a disconnect between the oil switch and bus, thus securing a high space factor. The adjustable contact and holding clamps enable the switch to be so located that a short run is secured to the oil circuit breaker terminal. This type of switch is made for any desired capacity flat or round bus.

Outdoor Units.—The "Unit Type" idea has been extended to outdoor equipment for all commercial voltages. A complete line of bus bar supports, wiring supports, disconnecting switches, choke coils and fuse mountings have been developed.

The voltage ratings conform to the standard commercial pressure of 6600, 13,200, 22,000, 33,000, 44,000 volts. The following tabulation shows the insulation strength of bus bar supports for different voltages.

"Unit Type" Insulator Characteristics

Normal-rated voltage	Tested at	Normal factor of safety
6,600 volts	30,000 volts	Approx. 4 : 1
13,200 volts	54,000 volts	Approx. 4 : 1
22,000 volts	75,000 volts	Approx. 3 : 1
33,000 volts	100,000 volts	Approx. 3 : 1
44,000 volts	125,000 volts	Approx. 2¾ : 1

Wire and Cable.—For the main connections between the various parts of the switch gear and the generators, feeders, etc., cables or wires are frequently used and most of the larger manufacturing and operating companies have standardized their specifications for cables and wires. These naturally differ with different concerns but in most cases they have been based on specifications adopted by the National Fire Protection Association or some similar body. In most cases two styles of rubber-insulated braid-covered cables or wires are available:—1. With one weatherproof braid. These are known as Rubber-Insulated Braid-Covered Wires and Cables. 2. With one weatherproof braid and an outer flameproof braid. These are known as Rubber-Insulated Flameproof Wires and Cables.

Standards.—The use of these standards in the selection of wires and cables will greatly facilitate delivery of such wires and cables. It will also avoid confusion due to the necessity of following special material, and changing the dimensions of bushings and terminals to fit special cables.

Sizes.—In order to keep the number of different kinds of cable in an installation within reasonable limits, when the difference in insulation thickness required for different voltages is not large, it is well to use the heavier insulation for both voltages, and to furnish a cable with more copper than is required for a given service rather than to order a special size. Where cable of a given size is required to have flexible stranding for some work, it is better to use it where a stiff stranding would be satisfactory, unless the amount of stiff stranded cable exceeds 1000 feet, so as to warrant ordering it special for use on the installation in question.

In ordering 600-volt, rubber-insulated wires and cables from manufacturers' stock, specify the capacity, "National Electrical Code Standard," and give the number of weatherproof braids desired. For example, 61 of .1145, 600-volt Code Std. Cable with two weatherproof braids.

Bends in Cables.—Care must be taken to see that the curve about which the cable is bent is large enough to prevent injury to the insulation. The radius of the smallest curve about which bending is recommended for cables is usually given; a larger radius is much preferable, as the larger the radius the less liability of injury to the insulation at the bend.

Three-Conductor vs. Single-Conductor Cable.—For generator leads, where the current is small enough to permit the use of standard three-conductor cables, these are to be preferred to three single-conductor cables. All cables carrying heavy currents must be rigidly supported to prevent the cables being displaced by a severe short circuit.

Dry Places.—Up to and including 600 volts, single or multiple conductor, rubber-insulated, or varnished cambric-insulated, flameproof cables should be used. When cables are mounted directly upon a switchboard panel, the slate or marble panel is considered as an insulator and it is not necessary to mount the cables upon additional insulators.

For service over 600 volts and up to and including 15,000 volts single or multiple-conductor, rubber-insulated, or varnished cambric-insulated, flameproof cables are suitable. The flameproof covering does not provide much insulation and therefore should be treated as a conductor and stripped back a sufficient distance to afford ample creepage distance for the potential of the circuit. When the cable is in such short lengths that it would be necessary to strip off nearly all of the flameproof covering to obtain the necessary creepage distances over the surface of the insulation, cables with weatherproof braid may be used.

Small wiring for transformers, instruments, etc., may be cleated directly upon marble panels for circuits of not over 2500 volts, if suitable creepage distances are provided between conductors and to ground.

No standard has been adopted for service over 15,000 volts, some engineers demanding full insulation for the line voltage while others specify bare conductors.

Wet Places.—Up to and including 600-volts service single or multiple-conductor, rubber-insulated, or varnished cambric-insulated braid-covered cables can be used.

For service over 600 volts up to and including 15,000 volts, single or multiple-conductor, paper-insulated, rubber-insulated or varnished cambric-insulated, lead-covered cables are recommended, cables to be installed without insulators.

When it is necessary to use braid-covered cables, they may be either rubber, or varnished cambric-insulated, and must be mounted on insulators suitable for the voltage service.

No standard has been adopted for over 15,000-volts service some engineers demanding full insulation for the line voltage while others specify bare conductors.

Conduits.—Metal and bitumenized fibre conduits can be used for single or multiple-conductor, rubber-insulated, or varnished cambric-insulated, braid-covered cables.

When single-conductor cables are used on alternating-current circuits in metal conduits, all of the phases of the circuit must be installed within the same metal conduit.

Metal, cement and tile conduits are suitable for single or multiple-conductor, paper-insulated, rubber-insulated, or varnished cambric-insulated, lead-covered cables.

Bells.—End bells must be used on circuits of over 2500 volts, and should preferably be furnished on circuits of over 750 volts.

Where cables are supported on insulators below the floor (up to and including 15,000-volt service) and there is likely to be moisture, as on the ceiling of basements, etc., the following practice is advisable:

Single or multiple-conductor,-paper-insulated, rubber-insulated, or varnished cambric-insulated, lead-covered cables are recommended, cables to be installed without insulators.

When it is necessary to use braid-covered cables, they may be either rubber or varnished cambric-insulated, and must be mounted on insulators suitable for the voltage service.

Lead-Covered Cables.—In all cases, lead-covered cables are good for continuous service with lead grounded at the maximum voltage for which they are listed. The varnished cambric-insulated wires and cables have insulation in accordance with the practice of the responsible cable manufacturers. The underwriters have not yet prepared specifications for this class of wires and cables.

All rubber-insulated wires and cables purchased under specifications of certain manufacturers, with the exception of multiple-conductor cables, lead-covered cables, and a few special cables are provided with a separator of cotton yarn or paper between the rubber insulation and the copper to prevent the rubber compound from adhering to the copper. This facilitates stripping of insulation and soldering of conductors where joints are to be made.

CHAPTER XVI

BREAKER STRUCTURES

Where the direct-control switchboard is not employed but distant control oil circuit breakers are utilized for the main A.C. connections, the arrangement of the breakers, disconnecting switches, bus bars, etc., is of great importance, and on the proper location of these devices rests the satisfactory performance of the equipment.

Bus Arrangements.—To give a better idea of the difference between the panel mounted and the distant control arrangements

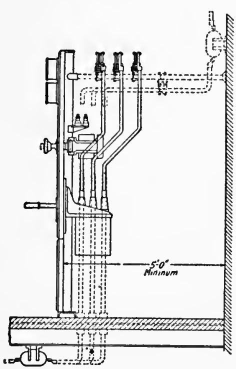


Fig. 243.

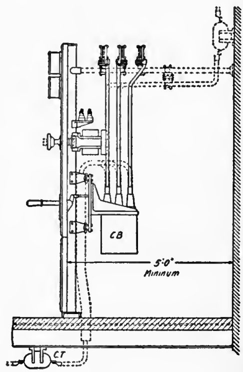


Fig. 244.

some typical layouts of different locations for breaker and bus are shown. Fig. 243 shows panel mounted oil breaker with bare bus and connections for service at voltages up to 750 volts, with bus directly over the breaker while for voltages above 750 it becomes desirable to have the bus higher than the head of the operator. Fig. 244 shows the corresponding schemes using the panel frame mounted breakers to get additional clearance and to remove the breaker from the rear of the board. This panel frame mounting gives a better construction, in that connections from circuit breakers to bus bars are more nearly direct and more space is available for taking away connecting cables to panels and for mounting switchboard details. Some of the other advantages are the following: less likelihood of oil getting on panels; the weight of breakers is carried on frame instead of on panel; the rear of the panels is more accessible; several types and capacities of breakers have interchangeable mountings; with narrow panels the position of the breaker handle is not restricted to the center of the panel so that knife switches and handles for remote control breakers can often be added where this would be impossible with direct panel mounting unless wider panels are used.

Unit Assemblies.—In designing the bus and oil circuit-breaker structures illustrated, endeavor has been made to assemble all the apparatus within a unit space, in order that a section may be considered a distinct piece of apparatus which may be located as a unit where desired.

The enclosed and semi-enclosed structures are designed to suit walls and barriers of concrete. In case brick structure is desired, the dimensions may have to be modified slightly to suit the sizes of brick used.

(*a*) *Open Construction—Frame Mounting.*—Each bus and circuit-breaker structure section with frame mounting breakers (2400 to 13,200 volts, consists of a $1\frac{1}{4}$-inch pipe framework together with necessary mounting brackets and supports for the equipment, consisting of oil circuit breakers, disconnecting switches, instrument transformers, bus bars, and connections.

(*b*) *Open Construction—Wall Mounting.*—When desired, equipments with frame or wall mounting breakers will be supplied by the switchboard builder with framework details omitted, and only connections from circuit breakers to bus bars, bus bar supports and terminals, wall braces, and brackets necessary to adapt the circuit breakers for wall mounting.

(*c*) *Semi-Enclosed Construction.*—When desired, the wall mounting or frame mounting breakers may be suitably enclosed and barriers added between the busses, forming a semi-enclosed structure. Such enclosures usually require a greater distance between adjacent breakers. When the equipments are to be installed in this manner, it is usual for the purchaser to provide the complete cells, top slab, doors, barriers and all cell material.

(*d*) *Enclosed Construction—Wall Mounting.*—The wall mounting breakers may be enclosed and separate fireproof compartments provided for all bus bars and main connections. Equipments with wall mounting breakers may be installed in this manner, the purchaser furnishing all material.

(*e*) *Enclosed Construction—Cell Mounting.*—Each bus and circuit breaker structure section with cell mounting breakers, as usually supplied includes a complete set of mounting and connection details, switching and transformer equipment, and cell mounting breakers suitable for an enclosed cellular construction, wherein there is provided a separate compartment for each circuit-breaker pole, bus bar, and main connection. Tie rods and channel iron base, when necessary, and breaker front cell doors are also included. Doors for other parts of the structure can be furnished. Structures for most of the wall or frame mounting breakers may also be designed to line up with the cell mounting breakers.

Frame and wall mounting breakers, 22,000 volts and over, which are usually arranged for open construction, frame mounting, are also suitable for open construction, wall mounting, and semi-enclosed construction, wall mounting.

Cell mounting breakers, 22,000 volts and over, may be arranged for semi-enclosed construction or enclosed construction.

Floor mounting breakers are designed for open construction and are not readily adaptable for enclosed or semi-enclosed construction, although such designs are possible if desired.

Limits.—The remote mechanically controlled switchboard is limited in capacity by physical rather than electrical characteristics. As nearly all high capacity circuit breakers may be arranged for remote mechanical control as well as electrical operation, the problem becomes one of mechanical arrangement in which it is usually very easy to meet the electrical requirements.

The choice of the proper form of structure for the apparatus which is to be remote-controlled and the satisfactory arrangement of the apparatus thereon presents a more difficult problem than does the design and arrangement of the panels themselves. The reason lies in the many practical forms of structure, and the large number of arrangements of the apparatus which may be made upon each of the various forms.

Equipment.—The following apparatus must usually be considered in choosing a satisfactory arrangement: Circuit breakers, bus bars and connections, rheostats, instrument transformers, fuses for potential transformer primaries and for main wiring when employed, and disconnecting switches. Before a proper choice can be made, a complete diagram, including all main wiring and all of the above apparatus, should be carefully made, according to the system of connections which has been adopted for the installation under consideration. From this wiring diagram should be selected the circuit which presents the most complications; that is, the greatest number of disconnecting switches, instrument transformers, etc., and, with the various practical forms of structure in mind, an arrangement should be worked out for this unit of the structure. If the remaining circuits have the same, or a less number of members in the same relative location in the circuit as regards the oil circuit breakers, the problem is solved and the remainder of the work is simply duplication. If the members in some circuits appear in other locations than those in the circuit chosen, each differing unit must be worked out individually, with a view, however, of forming them into a symmetrical and uniform structure. The choice of arrangement depends upon the capacity of the station, the cost, the available space, the voltage, the type of circuit breaker chosen, and the current capacity of individual circuits.

Wall Arrangement.—It should be remembered that wall arrangement may be more costly than the separate frame arrangement if large windows, which must be bridged by steel work, occur back of the board. Concrete or masonry structures may add considerably to the cost of floor construction and support on account of their great weight. The wall mounting arrangements occupy the least space but have the disadvantage of giving accessibility from one side only. For this reason and because of the great increase in available space for mounting various members of the assembly, the separate mounted structures are preferred where space can be found.

Breaker Mountings.—There are two kinds of circuit breakers as regards their mounting: those designed for wall or pipe frame mounting and those for cell mounting. Any of the former may be enclosed in cells if desired. By the latter is meant those circuit breakers assembled from unit poles, each pole being designed to occupy a separate cell.

Electric Control.—All the advantages gained by the use of hand operated remote mechanical control breakers over switchboard-mounting breakers are applicable to the electrically operated breaker installations. The space required for breakers and bus bars for a given capacity will be practically identical, but due to the absence of operating rods, bell cranks, etc., arrangements and designs of structures can be used that are not possible otherwise and that present various adaptations to certain desirable building designs, which are out of the question with hand operated remote control breakers. This is particularly evident in large stations where high tension voltages such as 2400, 6600 and 11,000 are used for generators, and where extra high tension voltages such as 22,000, 44,000, 66,000, etc., up to 150,000 are employed for distributing circuits. The variety of structure arrangements with electrically operated circuit breakers is almost unlimited, but good operating practice has evolved certain typical designs which are illustrated in the following cuts and a brief discussion will be given for each arrangement shown.

Structure Types.—In general it may be stated that there are six general types of structure arrangements in use:

1. Wall mounting—All apparatus and bus bars either mounted directly on or supported from a wall of the building.

2. Framework mounting—All apparatus and bus bars mounted on a framework of iron pipe or structural steel shapes.

3. Combination wall or framework mounting.

4. Concrete or masonry structure mounting—all apparatus mounted in cells.

5. Combination concrete and structural mounting circuit-breaker in cells, with bus bars, etc., on iron framework.

6. Floor mounting and structural mounting—circuit breakers set on floor, with bus bars, etc., mounted on iron framework.

Designs.—The illustrations show the use of the solenoid operated circuit breakers chiefly, and have only considered a few motor operated breakers. It will be noted that breakers of relatively small breaking capacity and of voltages up to 13,200 and having a single frame for all poles with a single tank, have the solenoid mechanisms fastened directly to the frame of the circuit breaker. This makes the breaker a more or less self-contained unit. The remaining breakers which are built with each pole a separate unit with its own frame and tank are operated from one solenoid acting on a common operating mechanism to which each pole is connected.

Small 6600 Volts.—Fig. 245 shows typical structures for both single-throw and double-throw bus systems, with disconnecting switches on one side of the breaker, for installations for voltages up to 6600 and of relatively small capacity. These

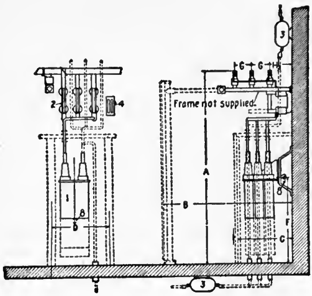


Fig. 245.

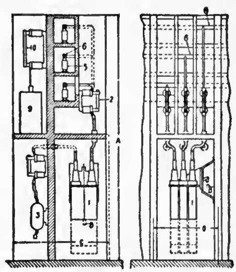


Fig. 246.

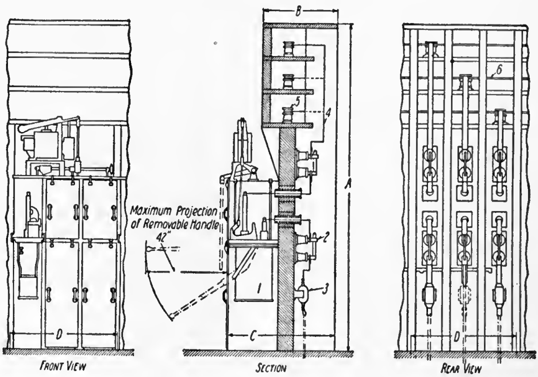


Fig. 247.

breakers have the self-contained solenoid mechanism as part of the circuit breaker framework.

Small 2200 Volts.—Fig. 246 shows the next size frame breaker which has all poles in one frame but separate tanks for each pole. This breaker, being heavier, makes it desirable to have the solenoid mechanisms remote from the breaker, as shown. This type of breaker can be used with voltages as high as 22,000 where the total station capacity is small enough so as not to require the use of a cell structure for the breakers.

6600-Volt Cells.—The front, rear, and side views of a structure for 3-phase, 6600-volts, solenoid operated breakers are

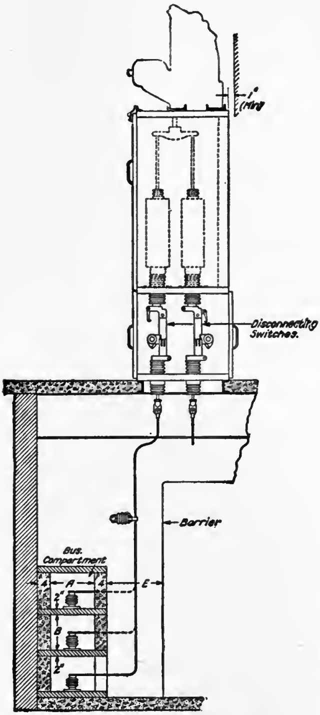


FIG. 248a.—Masonry compartments for motor operated breakers. (See Fig. 248b and c.)

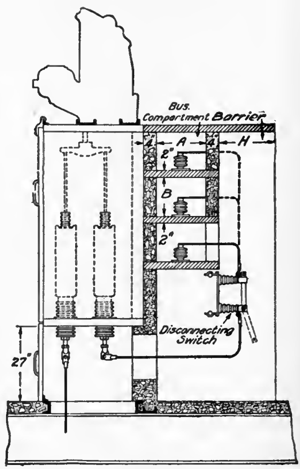


FIG. 248b.

shown in Fig. 247. The fireproof masonry compartment, bus bars, connections, etc. are separated by shelves, walls, septums, etc., in such a manner that no two conductors of opposite polarity are in the same compartment. The bus bars and laminated copper straps are supported on pillar type insulators resting on the shelves and bent copper strap forms the connections from the bus bars to the disconnecting switches and breakers. The disconnecting switches are front connected, mounted on porcelain pillars attached to a steel base located on the rear wall of the circuit-breaker structure.

With the type of breaker shown employing solenoid operation, the leads are brought out at the top of the breaker tanks, taken through the rear walls and the connections can then be run either up or down.

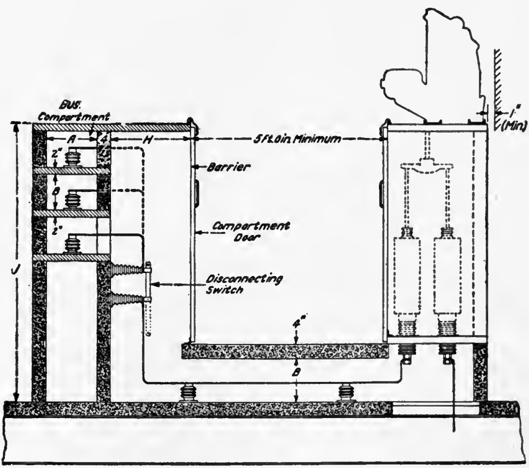


Fig. 248c.

Structures for Motor Operated Breakers.—Fig. 248 shows typical ways for arranging bottom connected, motor operated, 13,200-volt oil circuit breakers for connecting to the bus bars placed below them, (A) back of (B), or independent of (C) structure containing the breakers. A modification of this breaker used particularly when the leads are to run upward has the connection brought through the rear wall from the top of the cylindrical pots. Where both leads are to run upwards the two pots of each pole are arranged in tandem so that the six pots of a 3-pole breaker are all in one continuous line.

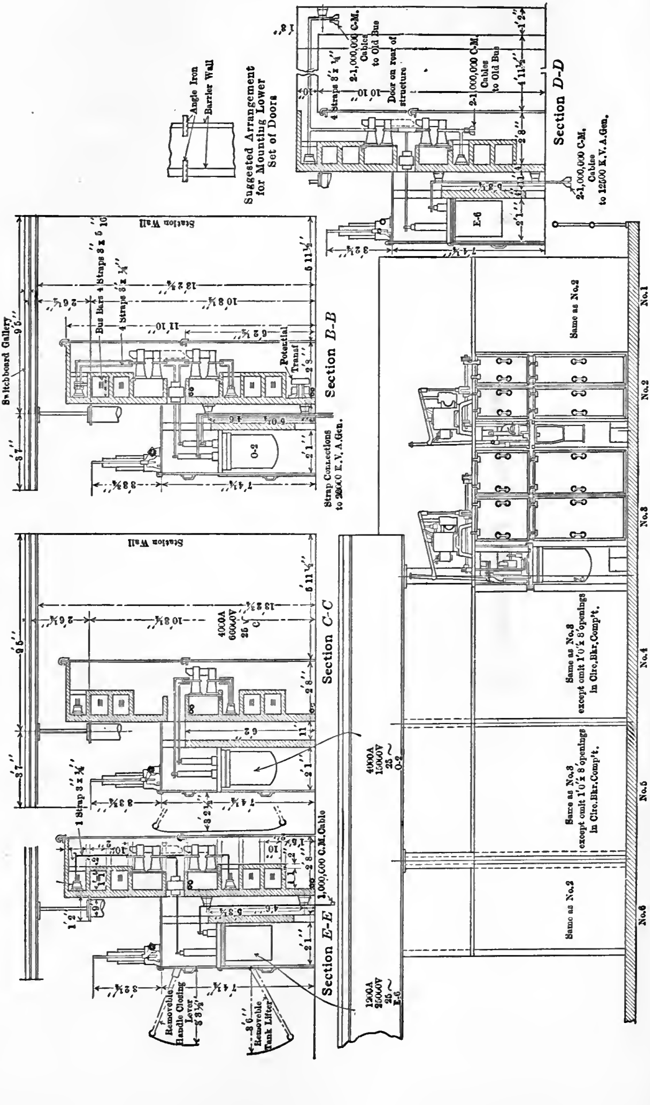


FIG. 249.—4000-volt structures, front & sections views.

4000-Volt Installation.—Fig. 249 shows a front view, rear view, and section of a heavy capacity 4000-volt installation with two sets of bus bars and a double-throw arangement carried out with two sets of disconnecting switches and one breaker per circuit. Due to the fact that the bus and breaker structure had to be placed under an existing gallery and that the posts of the gallery could not be disturbed, space was left between the breaker structure and the bus structure for the gallery posts and this space was also utilized for the generator and feeder connections. As shown on the rear view, breakers 1 and 2 were of 1200-amperes capacity, the breakers having oval tanks and being guaranteed capable of rupturing 52,000 amperes at 4500 volts. Breaker No. 3 in the circuit for a 22,000-K.V.A. generator had cylindrical tanks 20 inches in diameter and the breaker was guaranteed to rupture 112,000 amperes at 4500 volts. As shown in the sectional views for the first three breakers, connections were run up in the opening between the breaker structure and the bus structure to one of the breaker terminals. The other terminal of the breaker was connected by strap passing through current transformers and two sets of disconnecting switches either to the upper bus or to the lower bus. Breaker No. 4 was used for sectionalizing the lower bus. Breaker No. 5 for connecting together the upper and the lower bus, and breaker No. 6 controlled a 12,500 K.V.A. generator. This structure has been considerably extended to control additional generators and feeders.

22,000-Volt Structure.—Fig. 250 shows a section thru the switching galleries of a 22,000-volt installation where the generator breakers with their disconnecting switches and bus bars are located on the second floor and the feeder circuits, duplicate busses, and two sets of disconnecting switches are located on the first floor. The breakers for this installation were guaranteed capable of rupturing 5750 amperes at 25,000 volts.

Influence on Station.—While the breaker and bus structures in certain plants can be considered independently of the balance of the equipment in the station it is usual in large plants to give careful consideration to the effect of the switch gear arrangement on the entire design of the station.

In considering the effect of the structure arrangement on the balance of the system, stations may be considered as generating, converting, and transforming stations. In generating stations provision has to be made for the generators with their prime

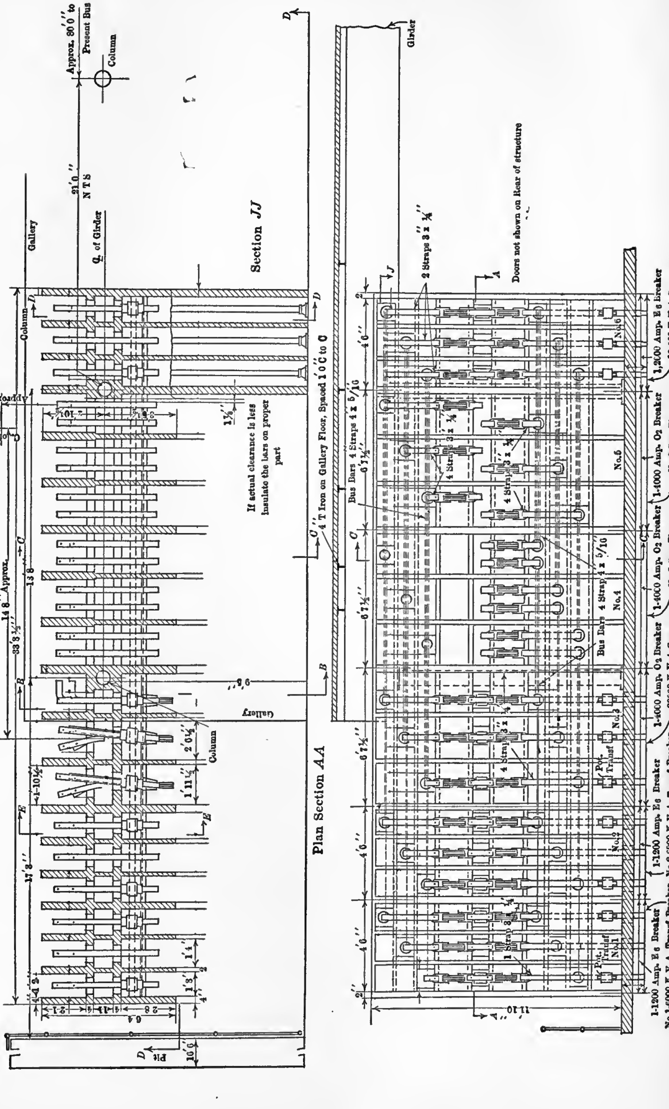


FIG. 249a.—4000-volt structures, plan and rear views.

movers and auxiliaries as well as for the switching equipment which may or may not occupy much space. In converting stations with converters or motor-generator sets the apparatus

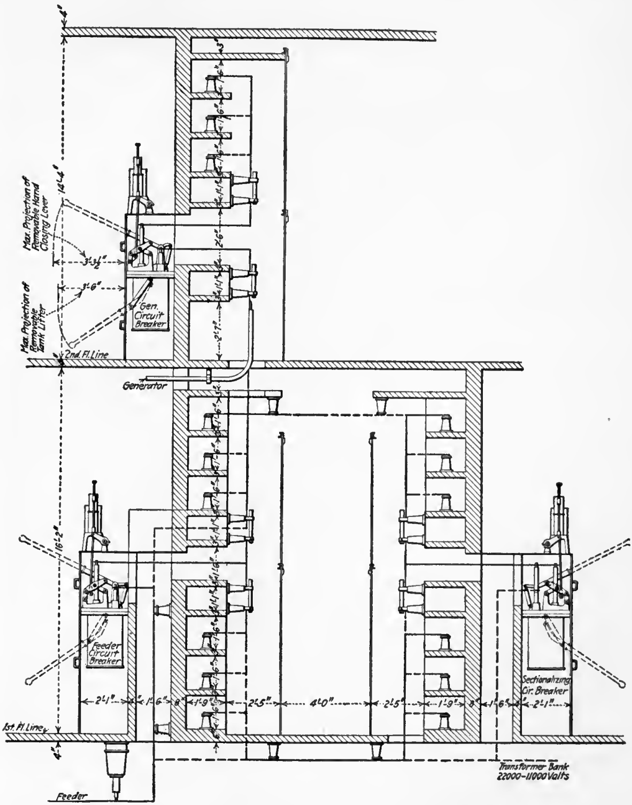


FIG. 250.—Masonry compartments for 22000 volts.

can usually be located to better advantage and arranged to simplify the wiring and switching equipment. In transforming stations where the bulk of the power passes through step up or step down transformers the switching apparatus can usually be so located with respect to the transformers as to secure the most satisfactory results. These transformer stations may be indoor or outdoor.

Certain features of the effect of circuit breaker and bus bar arrangement on the balance of the station can be considered to advantage in connection with a book on switch gear in place of one on general station design.

Locations.—In stations that distribute current at the generator voltage there are three usual locations for the oil circuit breakers and bus bars, depending principally on the amount of space needed for this portion of the installation. Those locations are at the end of the building, the sides of the building, or in a separate switch house.

End of Building.—This is a favorite location for the switch gear when the number of feeders is such that this location provides sufficient space for the breakers and the bus bars, making due allowance for probable future additions. With this arrangement it is customary in large plants to provide a number of galleries for the switching equipment. The switchboard is usually placed on one of the upper galleries so that the switchboard operator can readily watch the operation of the machines which he is controlling.

Side of Building.—Where the end of the building does not provide sufficient space the switching equipment is frequently located along one of the side walls, usually the side remote from the boiler room, in a steam station or the incoming penstock in a hydraulic station. The switching equipment when arranged in one or more galleries along the side of the building can easily be extended as the space available for the switch gear increases proportionately with the space available for the generating equipment if the building is lengthened. With this arrangement it is usually customary to locate the generator breakers directly opposite the individual machines and to run the bus bars the length of the station. With this arrangement the length of the generator leads will be reduced to a minimum and it is sometimes possible to use bare conductors for these leads. The switchboard itself, if electrical operation is provided, may be located either on one of the side galleries or at the end of the building in such a position that the switchboard attendant can readily watch the operation of the machine which he is controlling.

Switch House.—An extension of this scheme, namely, utilizing the side walls, is to provide a separate switch house and to control all of the apparatus electrically from a switchboard in the main building or from a switchboard in the switch house as preferred.

Section of Galleries.—Fig. 251 shows a section taken through the switching galleries of a large power house, and shows the arrangement of the oil circuit breakers, bus bars, series and

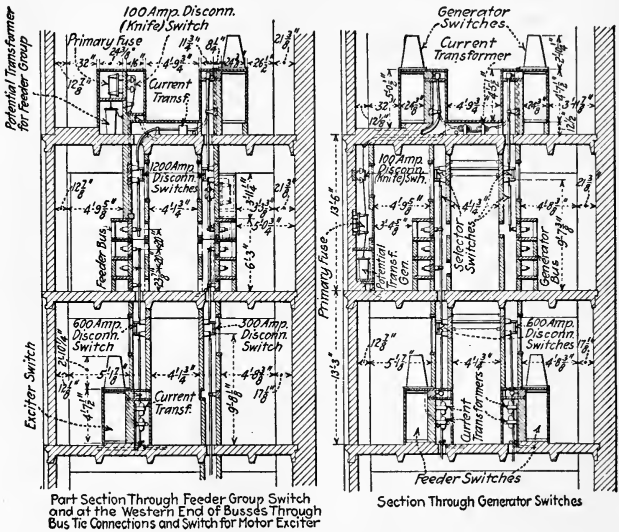


FIG. 251.—Section of switching galleries.

shunt transformers, etc. As may be noted, the bus bars are completely enclosed except for doors that are placed opposite each terminal and insulator, and in front of the disconnecting switches. This station has been in service since 1900.

As shown in the right-hand portion of the cut the generator circuit breakers are located on the top gallery and the leads are brought in suitable ducts to this point. The current transformers for the generator circuit are located under a false floor and the leads after passing through these transformers go into the oil circuit breakers, and then drop down through the floor to disconnecting switches, and to the bus bars.

In addition to the generator breakers on the top gallery, group breakers are also installed, while on the lower gallery are located the feeder breakers, and the bus tie breakers.

Two-phase Station.—Fig. 252 shows the front view and the section through the switching galleries of a heavy capacity 12,300-volt 2-phase generating station. This station contains the necessary switching equipments for the control of 8–8000-K.V.A. turbogenerators and forty feeders with a large number of local service circuits.

The connections are so made that each generator feeds through its own circuit breaker on to a generator bus, which generator bus can be connected through a second breaker to two sets of group busses, each group bus supplying current to five feeder circuits. The generator bus bars are located directly above the breakers in the upper gallery. The main bus bars are the top sets on the middle gallery and the feeder group bus bars are the lower sets on the middle gallery.

Ring Bus.—The bus structures are arranged back to back in such a manner that the main bus bars form one continuous ring sectioned by means of knife switches and circuit breakers while the group bus bars can be connected to form a second ring.

The bus bars in this station consisted of four copper straps each 3 inches by 1/8-inch in section per phase, these straps being supported on suitable porcelain insulators. For the connections between the circuit breakers, disconnecting switches and bus bars copper rod of suitable size was used.

With the arrangement shown in Fig. 252, the disconnecting switches for isolating the individual breakers are located in the masonry compartments back of the breakers so that it is practically impossible for trouble to arise due to the station operator pulling the wrong disconnecting switches when he desired to inspect or repair a breaker.

Top Connected Breakers.—These last two cuts, namely Figs. 251 and 252 show one of the advantages resulting from the use of top connected breakers with the leads brought out through the back wall, namely, the possibility of locating the bus bars between breakers on two different galleries.

These may be considered as typical arrangements—although old designs of actual plants—and indicate in a general way the

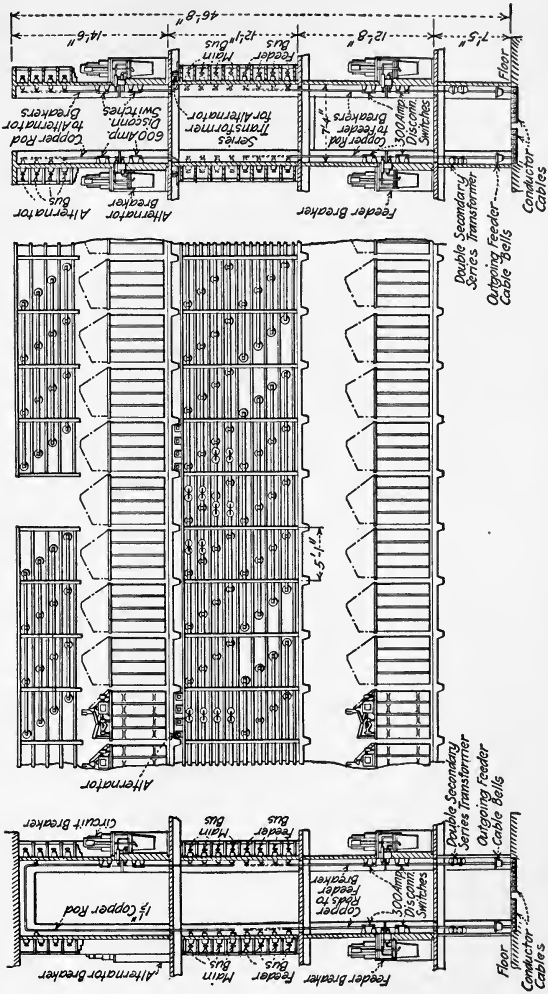


FIG. 252.—Gallery arrangement 2-phase station.

space allotted to this portion of the generating station in plants of large capacity. Each installation has to be considered on its own merits and the arrangement of circuit breakers and bus bars is a feature meriting deep study and careful design.

Synchronous Converter Stations.—The proper grouping of the apparatus in a synchronous converter station depends, of course, on the voltage of the A.C. circuit, size of converter, type of transformers and similar features and the building varies accordingly, provided the shape and size of the available lot is such as not to hamper the design of the station.

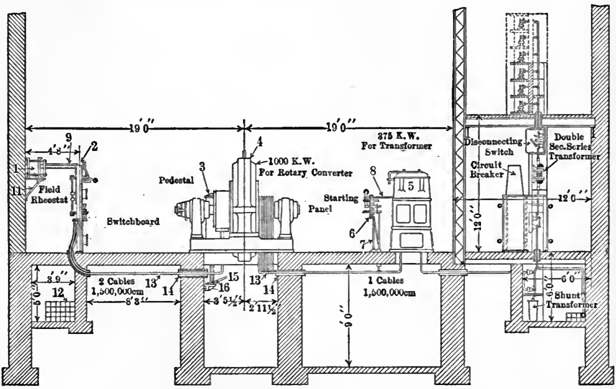


Fig. 253.—Sectional view of synchronous converter station.

Arrangement.—Fig. 253, shows the sectional view of a synchronous converter substation containing 1000-K.W. 6-phase converters with air blast transformers fed from 13,200-volt underground circuits. As may be noted the incoming leads from the cable ducts pass through an oil breaker and disconnecting switches to the bus bars that are located on a gallery, and provision is made for an additional set of bus bars and additional set of disconnecting switches to be installed at a later date so that any breaker may be connected to either of the two sets of busses.

The circuit from these bus bars passes back through other disconnecting switches and breakers to the high tension terminals located at the bottom of the air blast transformers. The low tension leads from the transformers go to a starting panel provided with double-throw switches that permit low voltage to be impressed on the converter for the purpose of starting and full voltage for running. The converters are provided with series field on the negative side, and the negative and equalizer switches are placed on a pedestal at the machine, and the negative and equalizer busses run on a bracket in the basement. The positive leads run to the panel board near the left-hand wall and the positive bus is located on the back of this board. The railway feeders are run out through underground ducts and the entire wiring of this station is very straight away from the high tension incoming lines to the low tension outgoing feeders. All of the high tension A.C. circuits are provided with electrically operated breakers controlled from the main switchboards. The entire design of this station hinges on the proper arrangement of the switching equipment.

M. G. Station.—A similar arrangement of stations can frequently be utilized to advantage where motor generators are used instead of converters and the circuit breakers for the motors can frequently be arranged along one side of the building and the corresponding switching equipment for the generators can be placed on the other side of the building and all of the apparatus controlled from a single control point. With such an arrangement the wiring is kept very straight and simple and the space is utilized to the best advantage.

Portable Substation for Converter.—Many interurban electric railways have portable substations located in freight cars and arranged for ready transportation to whatever point requires their temporary service. Fig. 254 shows a typical installation of this kind with a 500-K.W. 6-phase converter, 2—250-K.V.A. oil insulated self-cooling transformers and the necessary panel switchboard, high tension oil circuit-breaker and lightning protective devices in the 33,000-volt circuit. The general arrangement of the apparatus, method of wiring and other details are clearly shown in the cut. The operator standing in the middle of the car is convenient to the commutator end of the rotary converter.

Portable Substation for M. G. Set.—Fig. 255 shows a similar portable substation supplied to Brazil and containing a 50-cycle, 6600-volt, 3-phase synchronous motor direct connected,

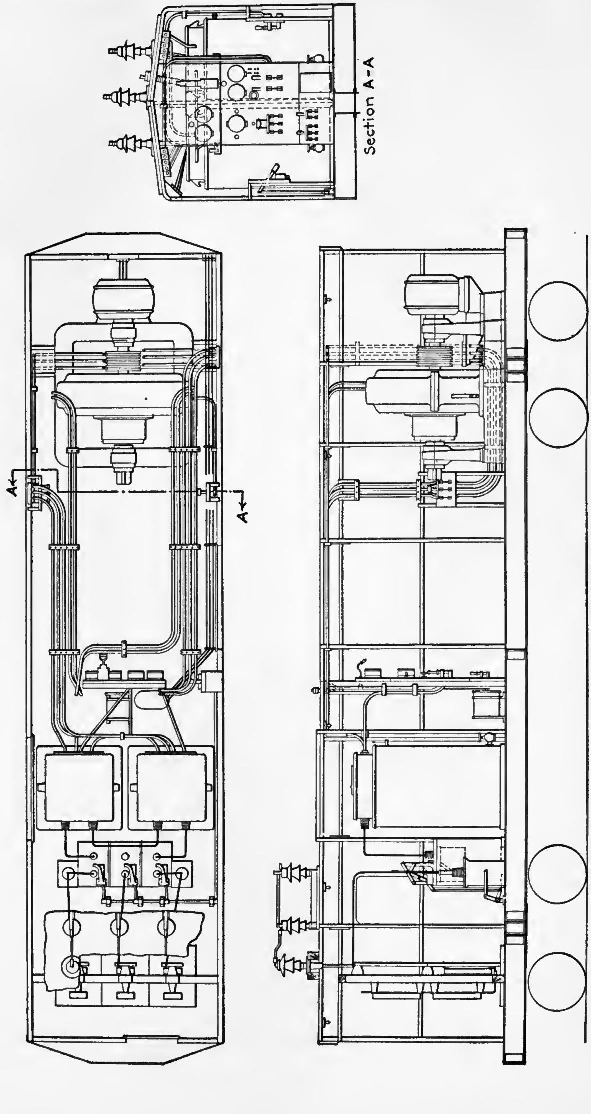


Fig. 254.—Portable substation for synchronous converter.

to a D.C. generator. The switchboard is provided with a panel for the self-starting synchronous motor with its exciter, a panel for the D.C. generator and 2-D.C. feeder panels. The difference in the type of car used is as noticeable as the difference in the arrangement of the apparatus which they contain.

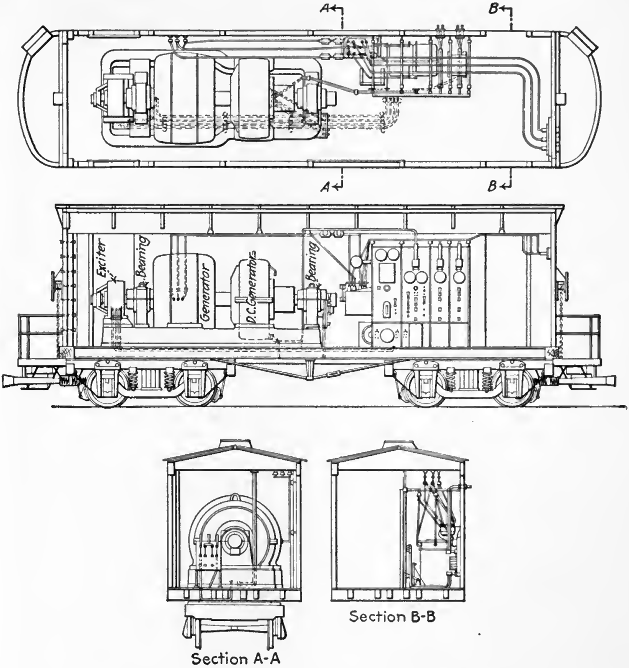


Fig. 255.—Portable substation for motor generator.

While the entire trend of American design during recent years has been to locate transformers and high tension switch gear out of doors, there are a few cases where, due to local conditions, indoor equipment is utilized.

Comparison Indoor and Outdoor.—For this reason, and to permit a direct comparison between high tension indoor and outdoor arrangements, a number of drawings have been selected

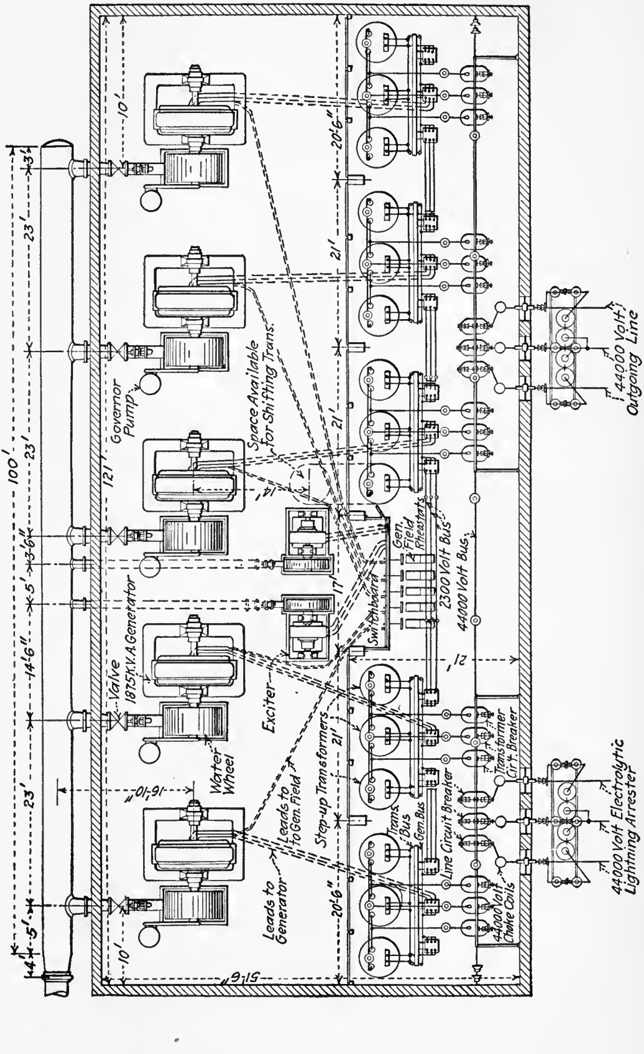


FIG. 256.—Plan view 44-K.V. station.

mostly of older design, showing the arrangement of hydro-electric generating stations for various voltages from 44-K.V. up to 110-K.V.

INDOOR STATIONS

44-K.V. Indoor.—Fig. 256 shows the plan view and Fig. 257 shows the sectional views of a generating station containing 5—1875 K.V.A. 3-phase horizontal shaft generators, 5 banks each of 3—625-K.V.A. 2300 to 44-K.V. step up transformers two 44-K.V. outgoing transmission lines and two water wheel driven excitors.

A panel switchboard was provided with electrically operated breakers in the L. T. and H. T. circuits.

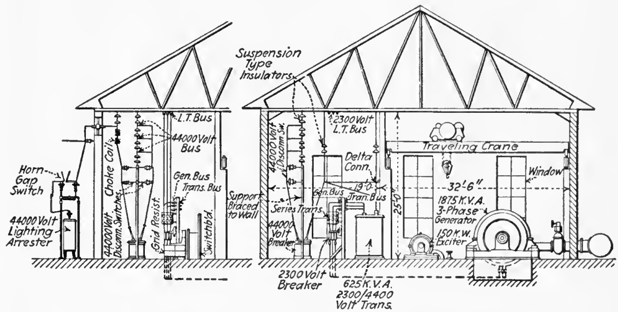


FIG. 257.—Sectional views 44-K.V. station.

The leads are taken from the generator as under ground cables to the L. T. switch gear. Each generator with its bank of transformers was provided with 3—electrically operated breakers so that the generator could be normally connected directly to its own transformer bank, or either generator or transformer could be connected to the transfer bus.

The transformer low tension delta bus is supported in the framework carrying the low tension breakers with their disconnects. From the high tension side of the transformers leads are taken through an oil breaker and disconnecting switches to a 44-K.V. bus, this bus being hung from a series of suspension insulators that are stretched between the roof girders and the steel work that carries the disconnecting switches above the 44-K.V. breakers.

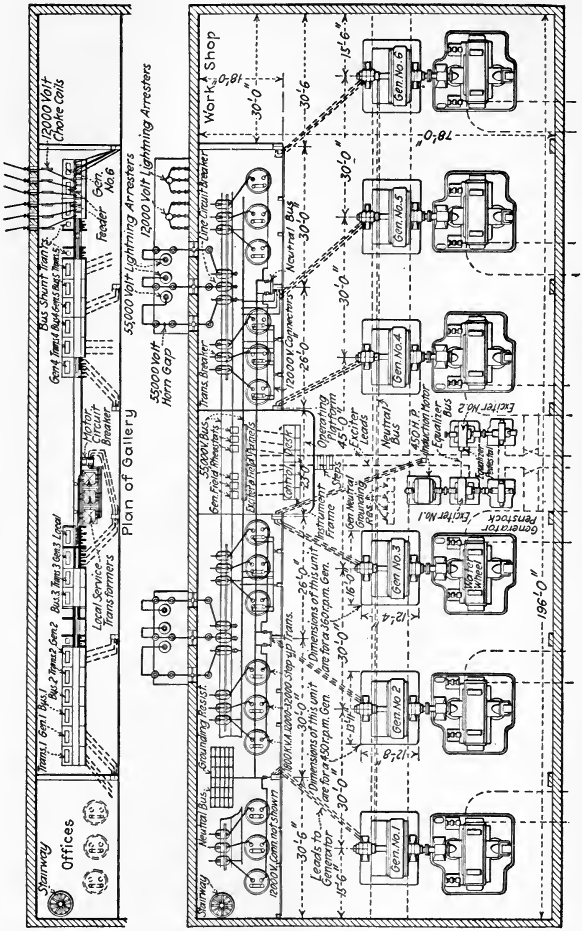


FIG. 258.—Plan view 55-K.V. station.

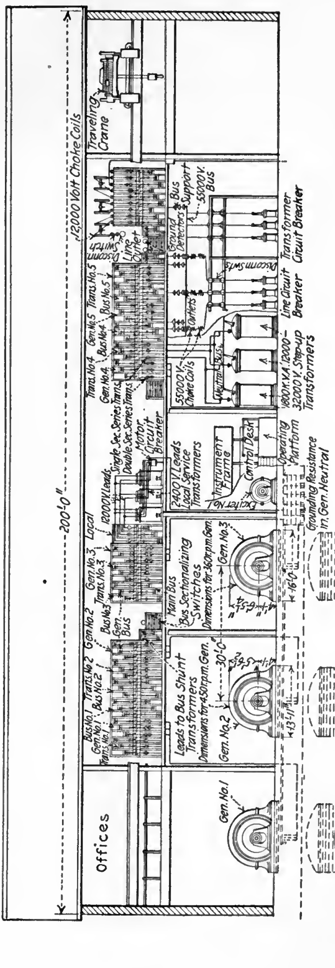


Fig. 259.—Longitudinal elevation 55-K.V. station.

From this bus, connections are taken through disconnecting switches, breakers, disconnecting switches and choke coils to the line outlet bushings set in the side wall. The electrolytic arresters are of the usual type located out of doors. The particular designs shown in Figs. 256 and 257 were prepared in December, 1909.

55-K.V. Indoor.—Figs. 258 and 259 show the plan views and sections of a 55-K.V. station whose designs were prepared in December, 1909. This station contains six 5400-K.V.A. 12-K.V. 3-phase generators, five banks each of three 1800-K.V.A. transformers, 12 K.V. to 32 K.V., delta connection low tension, star connection high tension for 55-K.V. service; two 55-K.V. feeders, two 12-K.V. feeders, one water wheel driven exciter, 300 K.W. 250 volts, one similar exciter that can be coupled either to a water wheel or to a motor; the motor being arranged for coupling to either exciter.

Provision was made for grounding the neutral of the generators by means of disconnecting switches to a neutral bus and this in turn connecting through a grounding resistor.

All of the 12-K.V. breakers are located in a gallery above the compartment containing the transformers and high tension switching equipment. The generator leads are carried up the columns that support the gallery and pass through the oil breakers to a main bus, or an auxiliary bus, and thence back to the low tension side of the transformers. The high tension leads from the transformers pass through oil breakers and disconnecting switches to a 55-K.V. bus that is hung from suspension insulators. From that bus connections are taken through disconnecting switches, oil breakers, other disconnecting switches and choke coils to the line outlet bushings.

The 12-K.V. and 55-K.V. lightning arresters are arranged for outdoor service.

The generators and main A.C. connections are controlled from a desk while the exciter and field circuits are operated electrically from the desk by means of breakers located on the exciter and field panels.

110-K.V. Indoor.—Fig. 260 shows the arrangement of a 100 K.V. generating station using 3-phase transformers.

This plant contains two 450-H.P. horizontal shaft water wheels, each driving a 300-K.W. 250-volt exciter, and six 9700 H.P. horizontal shaft water wheels, each driving a 7800-K.V.A.

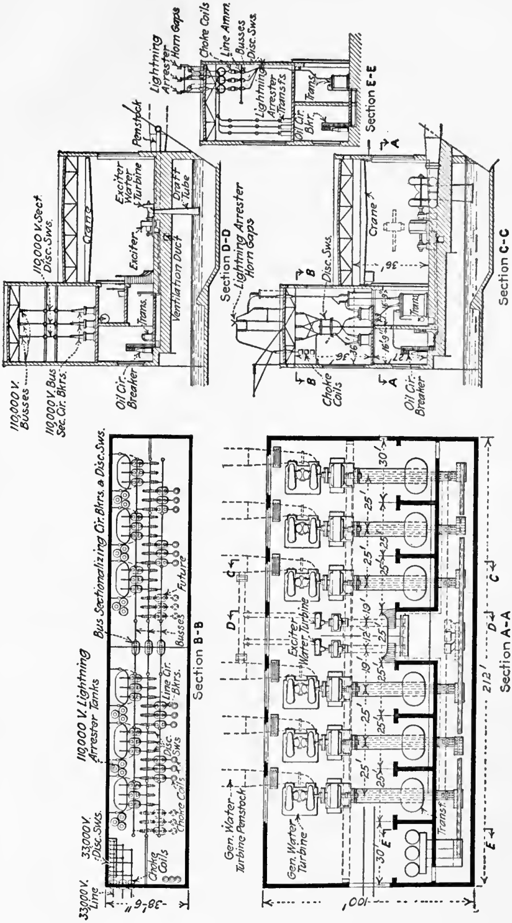


FIG. 260.—Indoor station 110 K.V.

4-K.V., 3-phase generator, and six 7800-K.V.A. 3-phase transformers, 110 K.V.

In this plant it was the intention that the generators should draw air in around the shaft and discharge it at the bottom of

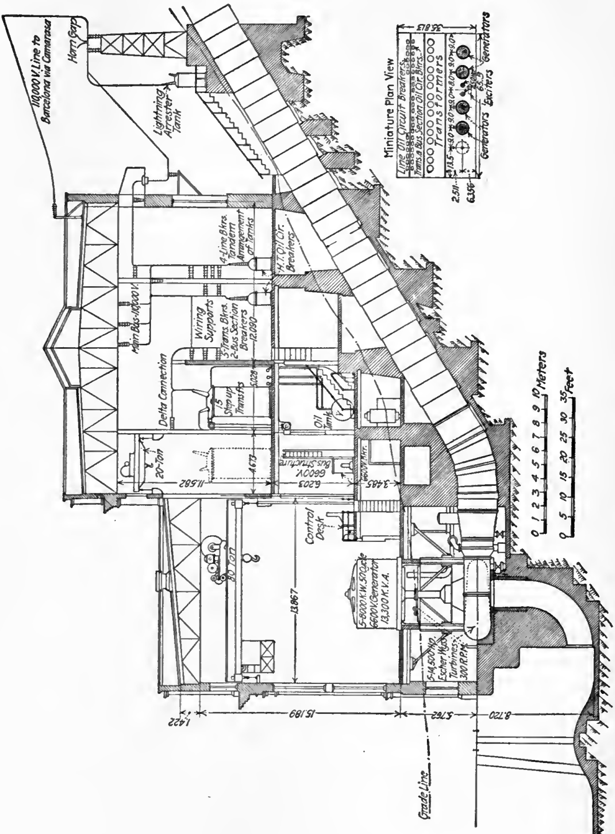


FIG. 261.—Sectional view Seros plant 110 K.V.

the stator to a short duct connecting with the tailrace. With this arrangment of discharging the heated air from the generators into the tailrace and locating the field rheostat resistors of the generator, outside the building as is sometimes done, the question of ventilation is considerably simplified.

The leads from the generators are carried to the low tension breaker and bus structure, thence to the low tension side of the transformers and from the high tension side through breakers to the high tension busses.

Alternative arrangements have been indicated locating the lightning arrester tanks indoor and outdoor.

This station was designed in March, 1911.

Spanish Stations 110-K.V.—Fig. 261 shows a sectional view through the 110-K.V. station at the Seros plant of the Ebro Irrigation & Power Company in Spain, this being the first installation in Europe to operate at a voltage above 100 K.V.

The plant contains four 14,500-H.P. vertical shaft water wheels with provision for a fifth, four 8000-K.W. 50-cycle, 6600-volt, 13,300-K.V.A. generators, with provision for a fifth, and four banks of 4444-K.V.A. 50-cycle single phase transformers stepping up to 110 K.V. for transmission to Barcelona. Plant was installed about 1911.

Fig. 262 shows the arrangement of the Tremp plant of the same system installed about 1913. This plant contains four 12,500-H.P. horizontal shaft twin turbines driving 8750-K.W. 14,500-K.V.A. 3-phase generators, having transformers with transmission lines at 110-K.V. to Barcelona and 25-K.V. from Pobla.

The operating gallery is arranged to overlook the generator room and the relay and recording instruments are mounted on panels back of the control desk. Back of the relay board are the low tension 6-K.V. circuit breakers with their bus bars and connections.

The high tension leads from the transformers are taken up through a floor opening to high tension breakers and then through disconnects to the high tension bus. Connections are taken from that bus to disconnecting switches and breakers, and thence out to the transmission line, the arresters being located on the roof of the building.

The high tension breakers in both of these Ebro plants have the tandem arrangement of tanks so that all six terminals of the 3-pole breakers come in one plane.

Montana Power.—Fig. 263 shows a sectional view through the Holter plant of the Montana Power Company, this plant hav-

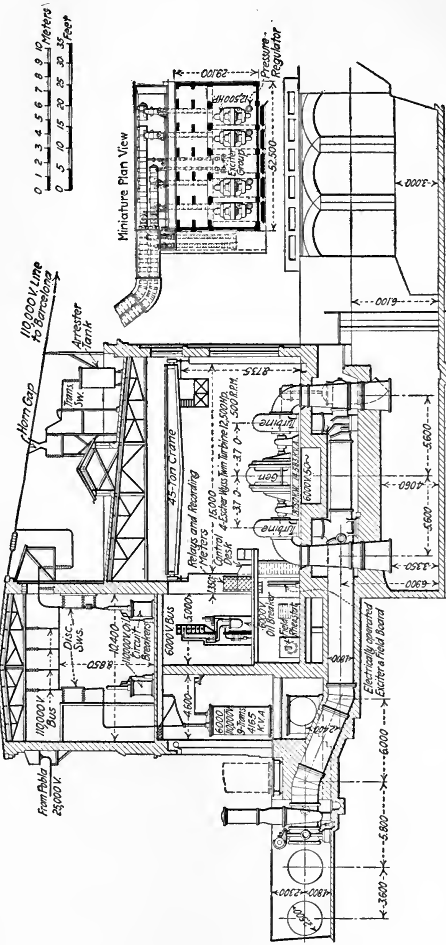


FIG. 262.—Sectional view Tremp Plant, 110 K.V.

ing been installed about 1916. The plant contains four 16,000-H.P. vertical shaft water wheels with 12,000-K.V.A. 6600-volt generators and four 3-phase transformers with a normal rating of 12,000 K.V.A. each, maximum rating of 16,000 K.V.A.

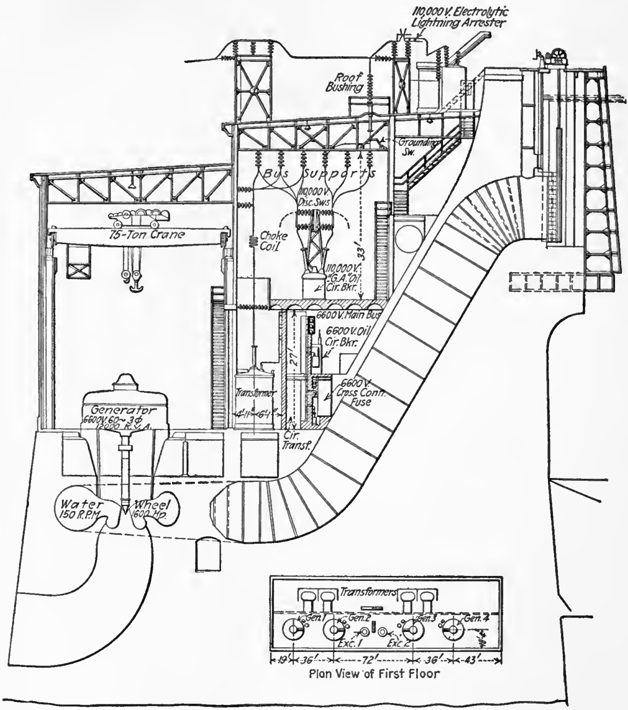


FIG. 263.—Sectional view Holter Plant, 110 K.V.

The leads from the generators are taken through the breakers to the 6600-volt main bus, back from that bus through similar breakers, or from the cross connection bus directly from the generators to the low tension side of the step up transformers.

The leads from the high tension side of the transformers are taken up through floor openings where they are attached between insulators and thence through choke coils and disconnecting switches to the high tension breakers, then to the bus and from the bus back to other disconnecting switches, breakers and disconnects through roof outlet bushings.

A grounding switch is located near these roof outlet bushings for grounding the high tension circuit, and the electrolytic lightning arresters are located on the roof of the building.

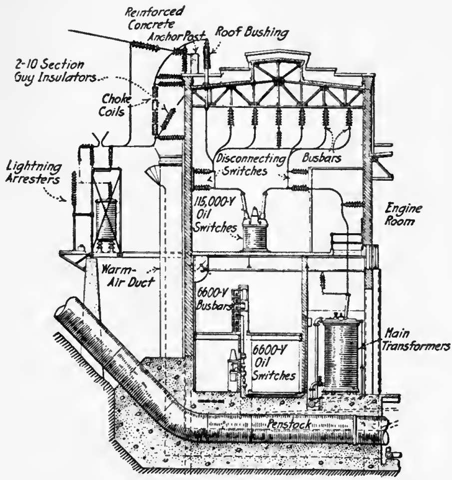


FIG. 264.—Transverse section. General Station, Inawashiro Hydro Electric Power Co.

Inawashiro.—Fig. 264 shows a transverse section through a portion of generating station of the Inawashiro Hydro Electric Power Company of Japan. This plant installed about 1915 contains 6–7700-K.V.A. 6-K.V., 3-phase generators, 12–4400 K.V.A. single phase transformers and two outgoing 115-K.V. transmission lines Power is transmitted a distance of 145 miles to Tokio where there is a receiving station whose original equipment included 12–4000-K.V.A. transformers stepping down to 11 K.V. for underground distribution.

Fig. 264 shows a transverse section through the portion of the building devoted to the transformers and the switching equipments. The incoming penstock to the water wheel passes under this portion of the building and the warm air passing from the generators is so arranged that it can discharge air into the switching galleries if needed there during cold weather or it can be discharged in such a way as to warm the lightning arrester equipment which is located out of doors.

The transformers are placed in masonry compartments and are so arranged that they can be pulled out into the power house where they can readily be lifted out by the crane which spans the generator room. The piping and valves for the water-cooled transformers are so arranged that they can readily be disconnected so that any transformer can be pulled out of the compartment into the generator room at the floor level so that it can be handled to advantage by the crane.

The relative location of the oil circuit breakers and bus bars in the 6600-volt circuit as well as the oil circuit breakers, disconnecting switches,bus bars and similar devices in the 115-K.V. circuit is evident.

Path of Current.—As may be noted from this drawing the current passes from the lower bus through the disconnecting switches into the oil circuit breaker, out through other disconnecting switches and current transformers to the cables carrying the current to the low tension side of the step up transformer. The high tension side of the step up transformer connections are taken to the high tension delta bus and the leads are then carried up through the floor by means of copper tubing. This copper tubing is mounted on the high tension wiring support. These connections then pass into the high tension breaker and through disconnecting switches to the high tension bus. Coming back from the high tension bus the current passes through disconnecting switches into the breaker, then from the breaker through other disconnecting switches to the line outlet bushing where the leads are taken through the roof and are then taken through the choke coils to the outgoing line circuit. The lightning arresters located outside the building are attached to the transmission lines outside of the choke coils.

The supports for the bus bars and wiring in the 115-K.V. circuit were made up of a number of insulators built into columns corresponding to the columns used on the disconnecting switches. These wiring supports were made of the rigid type instead of suspension insulators, to prevent any vibration that might be caused by earthquakes in the neighborhood of the station.

The 115-K.V. bus bars, wiring, and connections are made of copper tubing, ¾-inch gas pipe size having a nominal outside diameter of 1.04 and a nominal inside diameter of .78 inches.

This set of illustrations suggests various ways of arranging hydroelectric plants and locating transformers and high tension apparatus indoors. The portion of the building devoted to transformers and high tension switch gear can be readily determined and the expense of such portions of the building should be charged against the indoor installation when a comparison is being made between indoor and outdoor equipment.

In most cases it will be found that a considerably cheaper and better arrangement can be made by locating the transformers and switch gear out of doors.

A direct comparison between indoor and outdoor designs for 154-K.V. service is given later.

OUTDOOR STATIONS

While the arrangement of any outdoor station has to be determined from local conditions and the circuits to be controlled, a series of typical layouts have been prepared to show suggested arrangements for various voltages.

In order to cover as many different classes of arrangements as practicable, certain figures show single phase transformers and others three phase, some figures have water-cooled units, others self-cooling radiator type. Various features that appear on one figure can be utilized to advantage with the arrangement indicated on others.

22-K.V. Outdoor.—Fig. 265 shows a 22-K.V. transformer and switching station, for the control of 2–5000 K.V.A. and 4–10,000 K.V.A. 3-phase transformers feeding out over four 15,000 K.V.A. 22-K.V. transmission lines.

This station is arranged so that the high tension bus can be sectioned in the middle, one 5000-K.V.A. and 2–10,000-K.V.A. feeders being connected to each section. The sectionalizing of the bus permits shutting down half of it at a time for inspection, cleaning and repairs. By making the bus tie breaker automatic with instantaneous tripping under short-circuit conditions and providing the other breakers with definite time limit relays, arrangements can be made so that only half the station capacity will be concentrated on a short circuit.

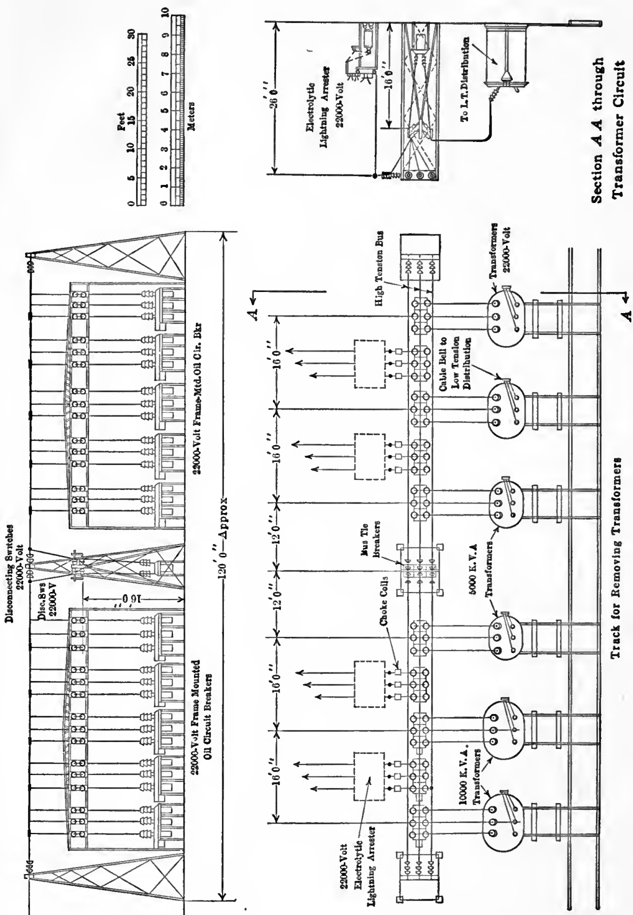


FIG. 265.—22 K.V. outdoor switching station.

Path of Current.—The incoming low tension circuits to the various transformers are controlled by suitable breakers in a low tension switch house adjacent to the high tension outdoor installation. The leads from the switch house are brought as underground cables in a tunnel to a point near the transformers and then brought up to suitable potheads supported independently of the transformer tanks.

The high tension transformer leads pass through disconnecting switches into an electrically operated oil breaker and pass out through a second set of disconnecting switches to the 22-K.V. bus. The circuit passes through disconnecting switches to the line breaker and through a second set of disconnecting switches and choke coils to the outgoing circuit, 22-K.V. lightning arresters are tapped off these outgoing lines. Disconnecting switches on each side of each high tension breaker facilitate the safe inspection of the breaker. Typical structural steel framework is indicated for the support of the disconnecting switches and busses. The arrangement of the steel work and the supporting towers is diagrammatic, no attempt having been made to figure the exact design of the various members.

While the high tension breakers are used in a 22-K.V. circuit the illustration has been prepared on the basis of utilizing 37-K.V. breakers to secure ample rupturing capacity for a 60,000-K.V.A. plant. 25-K.V. breakers would be slightly smaller than those indicated in this figure, while 50-K.V. breakers would be slightly larger, but the general appearance of a 33 or 44-K.V. transformer and switching station would correspond closely with Fig. 265.

66-K.V. Outdoor.—Fig. 266 shows a typical 66-K.V. transformer and switching station used with two banks each of 3–2000-K.V.A., O. I. S. C. radiator type transformers, with one spare transformer. This equipment is located immediately outside of a steam generating station and the low tension leads to the transformer banks are brought as lead-covered cable underground and up the outside of the building. The low tension delta is made at the transformers and a single bracket attached to the side wall is arranged to carry the insulators for the 66-K.V. delta connection as well as the insulator for the 13.2-K.V. delta connection.

Each transformer is on wheels, arranged so that it can be readily rolled onto a truck and the spare transformer pushed into its position. No provision is made by means of double-throw disconnecting switches to cut in the spare transformer in place of any other transformer.

Each transformer bank is supplied with one electrically operated frame mounted oil breaker connected through disconnecting

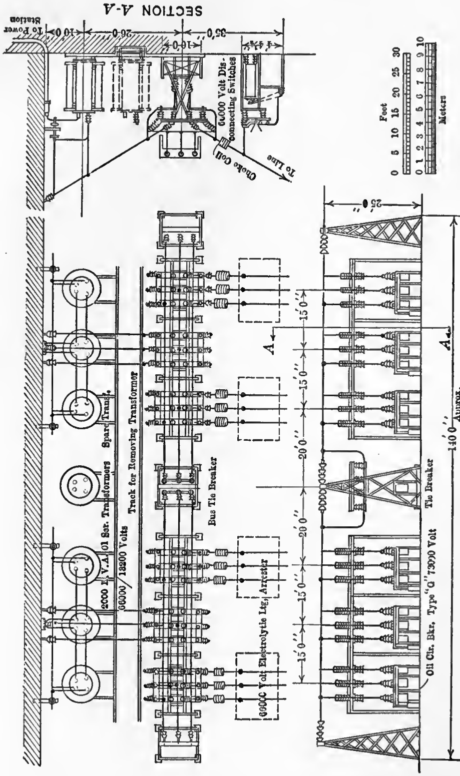


FIG. 266.—66 K.V. outdoor switching station.

switches to a 66-K.V. bus sectioned in the middle. This 66-K.V. bus in turn supplies a total of 4–66-K.V. outgoing feeders through disconnecting switches and oil breakers. Line suspension choke coils are connected into the outgoing feeder circuits and electrolytic lightning arresters are tapped off of these circuits. The oil circuits breakers indicated on this drawing are the 400-ampere, 73-K.V. frame mounted breakers. This layout is based on that of an installation in the Middle West.

88-K.V. Outdoor.—Fig. 267 shows a typical 88-K.V. outdoor switching equipment used in connection with two 7000-K.V.A. 3 phase, oil insulated, self-cooled radiator type transformers. There are two high tension incoming lines connecting through

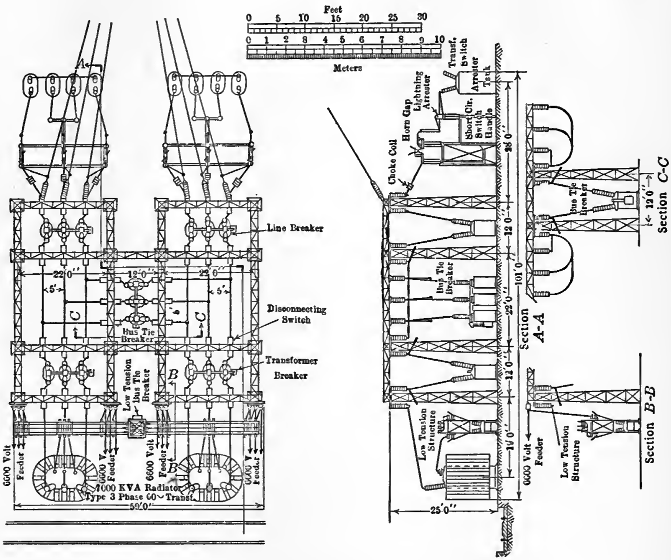


FIG. 267.—88 K.V. outdoor switching station.

disconnecting switches and oil breakers to a high tension bus, sectioned in the middle by means of a breaker. Each section of bus connects in turn by disconnecting switches and a breaker to the high tension side of a 7000-K.V.A. transformer.

The 6.6-K.V. side of each transformer connects through disconnecting switches and oil breakers to a low tension bus that is also sectioned in the middle. This 6.6.-K.V. low tension bus supplies current to four 6.6-K.V. outgoing feeder circuits. For this installation the low tension breakers and busses as well as the high tension breakers and busses have been shown as being of the outdoor type.

The oil circuit breakers indicated for use in the 88-K.V. circuits, are the 400-amperes, 95-K.V. breakers.

The disconnecting switches in the 88-K.V. circuits are of the normal inverted single-pole type to be operated from the ground by means of a long pole.

110-K.V. Outdoor.—Fig. 268 shows in plan view, a typical 110-K.V. outdoor transforming station used for the control of

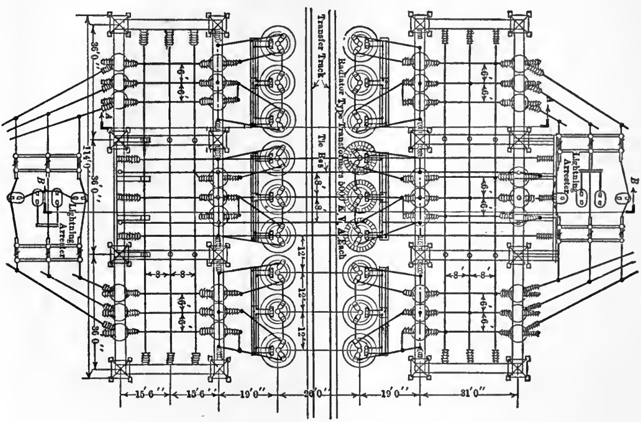


Fig. 268.—Plan view 110 K.V. outdoor station.

4—110-K.V. transmission line circuits and six banks of transformers, each of 3—5000-K.V.A., O. I. S. C. radiator type units. The arrangement shown is a slight modification of an actual installation that has been operating in the South for a number of years, and the location and type of disconnecting switches corresponds with those in service.

For this station all of the low tension switching is controlled by means of breakers located in a low tension switch house adjacent to the high tension transformer yard.

Section.—The high tension leads from each transformer, as shown in Fig. 269, are taken through disconnecting switches to a 115-K.V. round tank oil breaker. The leads from the transformer oil breakers then pass through other disconnecting switches to the 110-K.V. bus at the same time tapping across to the disconnecting switches and breakers for the outgoing line circuits.

The two sets of 110-K.V. bus bars, one on each side of the railway transfer track can be connected by means of the oil breaker in the outer row at the right center as shown by section B.B.

This installation contemplates 4—110-K.V. line circuits and to reduce the cost of the arrester equipment each pair of lines,

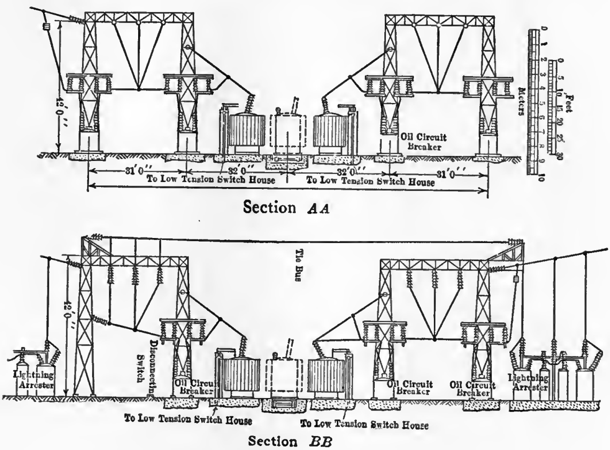


Fig. 269.—Section view 110 K.V. outdoor station.

which normally operate in parallel is provided with two sets of horn gaps, but only one set of arrester tanks with their oil, trays and electrolyte.

Disconnecting switches of the inverted single-pole type, pole operated, or of the inverted or upright, multiple pole, mechanically operated type can be substituted, if desired in place of those shown, and would usually be considered preferable, owing to the inherent weakness of a long heavy porcelain column in a position of a practically horizontal cantilever beam.

132-K.V. Outdoor.—Fig. 270, shows in plan view, a typical 132,-K.V. transformer and switching station. In this station, there are two banks, each of 3—10,000-K.V.A., single-phase transformers, 11-K.V. low tension voltage, 132-K.V. high tension voltage with 2—132-K.V. outgoing transmission lines running up the side of the hill. This arrangement is based on the Windsor installation of the West Penn Power Company.

In this installation, the low tension leads are brought from the adjacent steam generating station in a cable tunnel to the transformers. The high tension transformer leads are carried over head between strain insulators and taps are taken down from

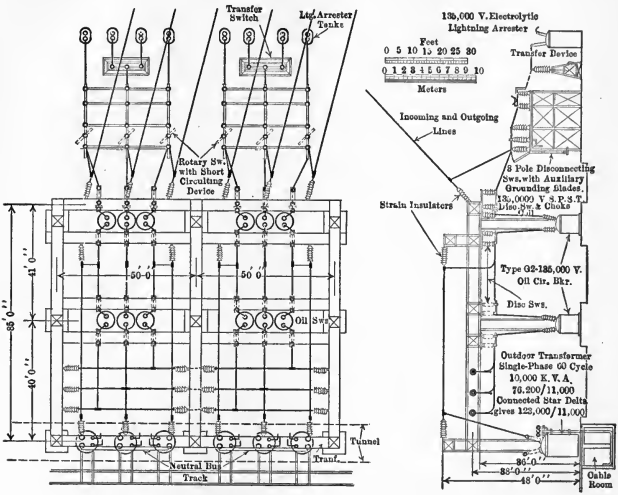


FIG. 270.—132 K.V. outdoor switching station.

these cross connections to the breakers and the current passes through disconnecting switches and breakers to the transmission line or can feed back through other disconnecting switches and breakers to a high tension transfer bus.

Provision is actually made in this plant for tieing together this transformer yard feeding one distributing system with its two 30,000-K.V.A. transformer banks to another transformer yard of slightly larger capacity feeding a different transmission system.

The disconnecting switches used for isolating the oil breakers are of the inverted type for pole operation. On the outgoing line breakers, a combination choke coil and single-pole disconnecting switch is utilized. As part of the lightning arrester equipment, mechanically operated 3-pole rotating type, double-break disconnecting switches with an auxiliary grounding device is furnished. Mechanically operated 3-pole disconnecting switches are usually preferable to any other type for voltages higher than 88 K.V. in so far as operation is concerned, but they normally require more elaborate steel structures to permit their satisfactory use.

Comparison Indoor and Outdoor.—To give a concrete comparison of transformer and switching stations for indoor and outdoor service at 110 K.V. and 154 K.V. Fig. 271 and Fig. 272 have been prepared to show typical arrangements in a large capacity water power plant to contain 6—22,500-K.V.A. generators, 6 banks each of 3—7500-K.V.A. single-phase step up transformers and 4—45,000-K.V.A. transmission lines. The portion of the building intended for the generators has been drawn up for both horizontal and vertical shaft units.

Indoors.—Fig. 271, shows the generating station with indoor transformers. On this drawing Fig. 1 shows a sectional view through the transformer and switch building to show the general location proposed for the transformers, oil circuit breakers, disconnectings switches, bus bars, lightning arresters and other apparatus. This portion of the drawing as well as the balance of the drawing has been made to scale showing the devices needed for the 154-K.V. installation. Two sets of dimensions have been marked in certain places, one giving the overall dimensions for 154-K.V. service, the other for 110-K.V. service.

Section.—As shown in the sectional view, Fig. 2, the 11-K.V. oil circuit breakers and bus bars are located back of the transformers, transformers being on wheels to permit their being readily rolled out into the generating station where they can be handled by the overhead crane.

The high tension leads from the transformers are taken up through floor openings and are mounted on suitable supports. These supports, as well as the piller supports for the disconnecting switches for indoor service, will probably be made of micarta tubing although possibly porcelain insulators built up in suitable columns may be employed.

The high tension neutral is run in the same compartment as the transformers.

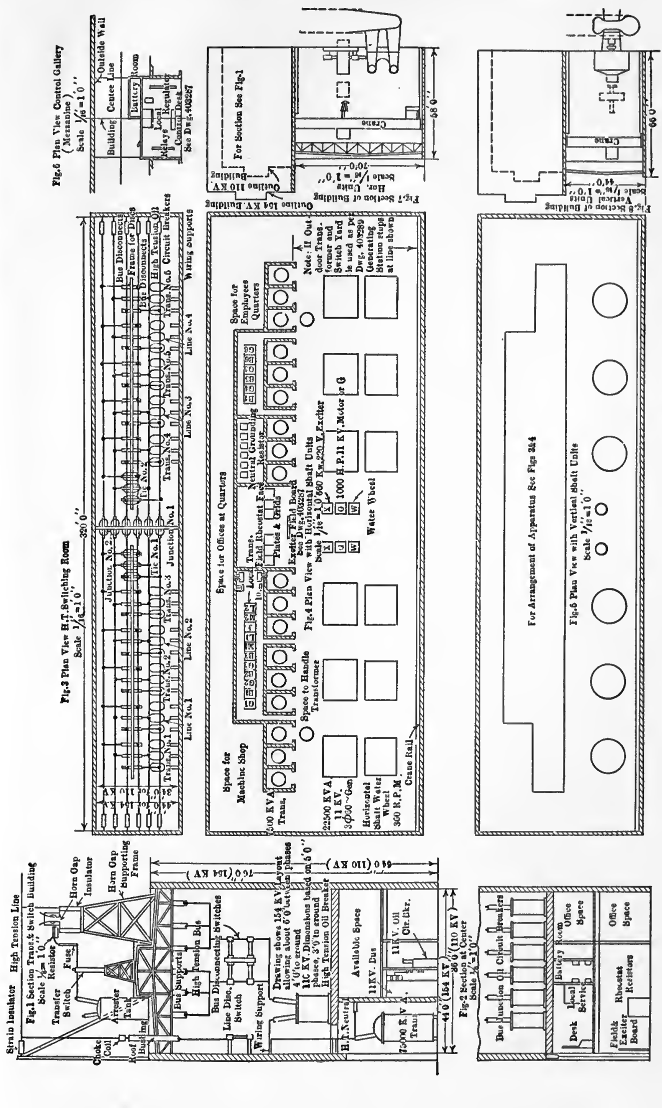


FIG. 271.—154 K.V. indoor type generating station.

The phase leads from the transformers after passing up through the floor openings go into the oil circuit breaker. From the oil circuit breaker they are taken through either of the sets of disconnecting switches to either of the two high tension busses. These high tension busses are suspended from the roof trusses in the manner indicated. These bus supports will probably be of the suspension insulator type although they may be a rigid built-up porcelain column, or possibly micarta tubing supports will be utilized.

From the busses the leads are taken back through the disconnecting switches through the oil circuit breaker, then to the line disconnecting switch, the roof bushing, choke coils, and thence to the high tension line.

The lightning arresters with their horn gaps, transfer switches and arrester tanks are located on the roof of the building.

Section at Centre.—On this same drawing, Fig. 2 is a section taken at the center of the building to show the location of the bus junction oil circuit breakers on the high tension gallery, the control desk, local service board and battery room on the mezzanine gallery, the field and exciter board and rheostat resistors on the lower floor.

Space Requirements.—A space the entire length of the generating station 320 feet long, has been allotted to the transformers and switching equipment.

For the 154-K.V. arrangement this portion of the building will have a height of 76 feet and a width of 44 feet, allowing about 6 feet between phases and 4 feet to ground.

For the 110-K.V. proposition allowing 5 feet between phases, 3 feet to ground, the portion of the building devoted to transformer and switching equipment would have a height of 64 feet and a width of 36 feet.

Plan H.T. Room.—Fig. 3 shows a plan view of the high tension switching room. As may be noted, the high tension oil circuit breakers are arranged in a row near the wall between the transformer house and the generator house, while the bus bars have beeen shifted slightly towards the outside wall of the building.

Space has been left available so that if desired breakers and disconnecting switches for two additional lines can be readily installed, one at the extreme right hand and one at the extreme left-hand end.

The tie breakers as well as the bus junction breakers are located near the central portion of the high tension switch room.

The high tension bus bars in addition to being suspended from the roof trusses as shown in the sectional view are held by strain insulators at each end of the building to minimize vibration.

Plan Main Floor.—Fig. 4 on this same drawing shows the plan view of the main floor of the power house using horizontal shaft water wheel generators and making the transformer house integral with the generating station. A note is placed on this Fig. 4 showing the location of the station wall if outdoor transformer and switch yard is used.

The various transformers have been indicated as being in transformer compartments, so arranged that any one transformer can be readily rolled out on its wheels to a point where it may be lifted by the traveling crane.

Outdoor Layout.—Fig. 272 shows outdoor transformer and switch yard. This drawing which has been made to scale showing the 154-K.V. installation has, in most places, two sets of dimensions, one giving the dimensions for the 154-K.V. installation, and the other for the corresponding 110-K.V. installation.

Plan View.—The bottom portion of the drawing shows the plan view location, the transformer bank, the four outgoing lines, the bus tie and junction circuits and similar main features.

Longitudinal Elevation. – On this plan view a center line marked '*EEE*' has been placed to show where the longitudinal elevation has been taken. This longitudinal elevation has been taken in such a manner as to show most of the important features, such as the horn gaps, the arrester tanks, the transformer banks with their neutral connections and neutral busses, the transformer oil breaker, the framework and supports for the selector type switches in the transformer and line circuits, the junction breaker, tie breaker, etc.

Line Equipment.—On the upper portion of the drawing, section '*AA*' shows the line equipment. As may be noted, connections are taken from the bus bars to short leads that are stretched between strain insulators attached to the lower framework and to the supporting framework of the selector switches. The leads pass thence to the outside studs of the selector switches and from the central studs to the wires that are held by the strain insulators attached to the tower structure. From these wires, the leads drop to the line breaker and from the line breaker

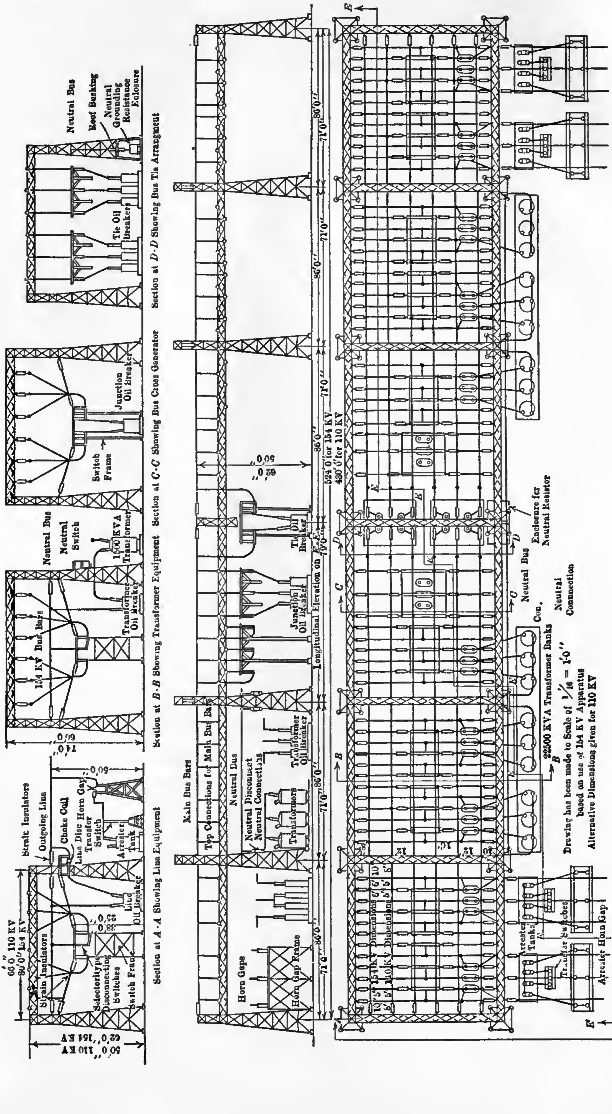


FIG. 272.—154 K.V. outdoor transformer and switchboard.

to the line disconnecting switch and choke coils, to the outgoing line circuit. The horn gaps, transfer switch and arrester tanks of the arrester appear on this sectional view.

Transformer Equipment.—Section at '*BB*' shows the transformer equipment and shows how the high tension lead passes from the transformer to the oil breaker, from the oil breaker to the wire that is stretched across the strain insulators attached to the tower framing. From this wire the leads pass to the central stud of the double-throw disconnecting switch. The outer studs of these switches are connected up to the busses in the manner shown.

Bus Connection.—Section at '*CC*' shows the bus cross connections while section at '*DD*' shows the bus tie arrangement.

Neutral Resistor.—With the outdoor equipment as shown on Fig. 272 the neutral grounding resistors will have to be housed in as they are not suitable for exposure to the weather The enclosure for the grounding resistor is made a portion of the central tower, and a suitable roof bushing is furnished for taking in the leads from the neutral bus to the grounding resistor.

Steel Work.—The steel work for the tower construction has been shown in merely typical form and the dimensions and spacings are more than ample. It is quite probable that a more detailed design of this outdoor transformer and switch yard would permit decreasing the height of the structure and possibly shortening up the width of the various spans.

This drawing, however, gives a fairly clear idea of one manner in which the transformers and switching equipment could be arranged for outdoor service to advantage.

Space Needed.—As may be noted, the tower construction for the 154-K.V. installation occupies a length of 524 feet on centers with a width of 80 feet, while the corresponding dimensions for the 110-K.V. equipment are 430 feet length and 86 feet in width. The height of the high towers will be 74 feet for use of the 154-K.V. installation, 60 feet for the 110, while for the shorter towers these dimensions will be 62 feet and 50 feet respectively.

It is considered quite probable that these heights may be reduced from 5 to 10 feet as the result of the closer calculations.

Cost of Building.—With the arrangement shown of Fig. 272 the space required for housing the transformers and switch gear for the 110-K.V. arrangement was 320 feet long, 64 feet high, 35 feet

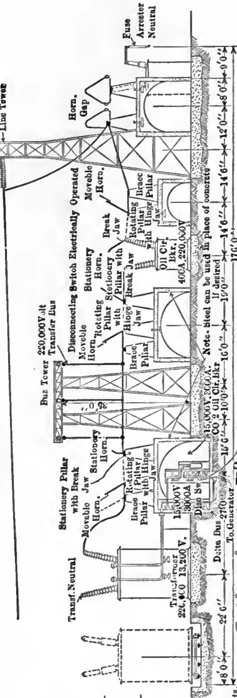


FIG. 275.—Section for 220 K.V. installation.

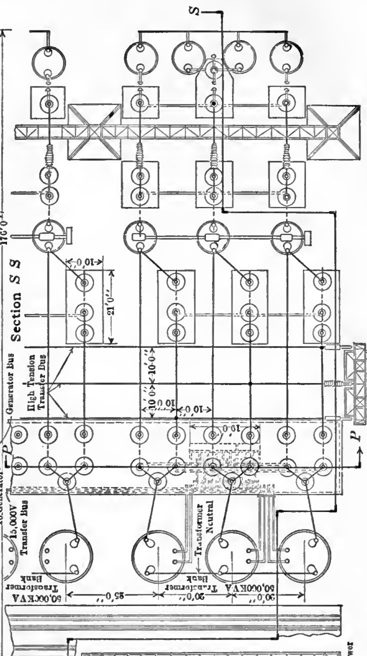


FIG. 274.—Plan view for 220 K.V. installation.

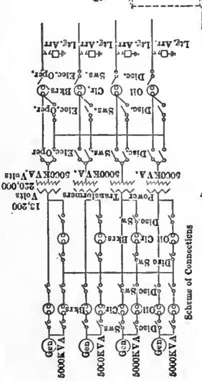


FIG. 273.—Diagram for 220 K.V. installation.

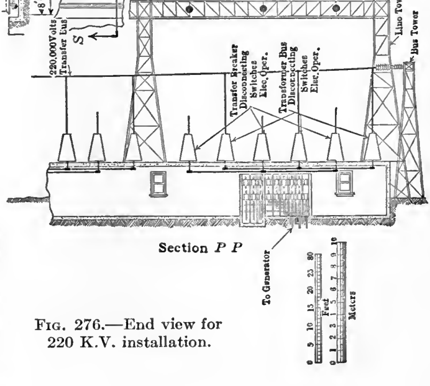


FIG. 276.—End view for 220 K.V. installation.

wide or a total of about 735,000 cubic feet. On the basis of twenty cents per cubic foot, this would cost about $150,000.

On the same basis, the corresponding portion of the station required for the 154-K.V. layout would have a cost of about $225,000.

The cost of the steel work erected, and the extra cost of making the 110-K.V. *A* apparatus suitable for outdoor service in place of indoor would amount to about $60,000 showing a net saving of about $90,000 for using outdoor equipment, while for the 154-K.V. proposition the net saving would be about $135,000. These figures are about 13 percent of indoor costs.

Figs. 273 to Fig. 276 shows the arrangements proposed for a typical 220-K.V. outdoor switching and transformer station.

Diagram.—A single line diagram, Fig. 273 shows the main connections proposed for this plant, that is to contain 4–50,000-K.V.A., 220-K.V. outgoing transmission lines. As shown in this single line diagram of connections, each generator with its transformer bank is provided with a total of three oil breakers with suitable disconnecting switches. The connections are so arranged that while normally each generator will tie in with its own transformer bank, any generator or transformer bank can be connected to the low tension transfer bus.

Switches and Breakers.—On the high tension side of the transformers the electrically operated, 3-pole disconnecting switches are provided with electrically operated breakers in the outgoing line circuits. Normally each transformer bank will be connected to its own outgoing line breaker but by means of the electrically operated disconnecting switches any transformer bank or any line breaker may be connected to the high tension transfer bus. The disconnecting switches were made electrically operated to facilitate their control from one central point.

Plan.—The plan view arrangement Fig. 274 shows the relative position proposed for the transformer banks, disconnecting switches, oil breakers, arresters, etc. While the elevation section *'FF'* shows somewhat more clearly the general relative location of these various devices.

Section.—The disconnecting switches shown in sectional view Fig. 275 have special insulator columns, each pole of a disconnecting switch normally requiring three columns. One supports the stationary contact and stationary arcing horn; one acts as a brace pillar, and the third is arranged to rotate in such a manner as to secure a vertical rotation of the switch blade and movable arcing horn.

As indicated in the plan view, the two 3-pole disconnecting switches adjacent to the transformer banks have their poles alternated and the two poles in any one phase have a common brace pillar, so as to reduce the number of insulator columns.

The disconnecting switch located near the oil breaker has each pole provided with its own set of three insulator pillars. The disconnecting switch used with the arrester horn gaps has its break jaw and stationary horns indicated as being mounted directly on the terminal of the oil circuit breaker.

The lightning arrester horns are mounted on similar pillar insulators and the central pillar carries a combination horn and transfer switch.

Elevation.—As shown particularly in the side and end elevation Fig. 276 the oil breakers in the 13.2-K.V. circuits are indoor breakers, these being located inside the hollow platform on which the insulators of the 220-K.V. disconnecting switches are mounted. These breakers are provided with suitable disconnecting switches and are arranged to tie onto a low tension transfer bus or connect a transformer direct to a generator as desired.

The low tension transformer leads in the form of copper strap are taken from the transformer delta bus out through the side wall of the concrete platform.

The path of the high tension connections from the transformer terminals through the disconnecting switches on the platform to the high tension bus or to the line breakers can be readily followed from the figure.

The oil breakers contemplated for this installation are 220-K.V. circular tank type breakers.

While the high tension disconnecting switches have been indicated as being operated by the rotation of one of their pillars, a somewhat different type of mechanism may be employed and the switches themselves instead of being mounted on concrete platforms may be located on steel structures.

These various drawings indicate typical methods of arranging large capacity outdoor transforming stations. Moderate capacity high voltage stations could be arranged in a somewhat simpler manner.

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